JOURNAL
OF THE
WASHINGTON ACADEMY OF SCIENCES

VOL. 48 February 1958 No. 2

GENERAL SCIENCE.—*A critique of operations research.* GEORGE E. KIMBALL, Arthur D. Little, Inc. (Communicated by E. W. Montroll.)

In spite of the fact that the Operations Research Society of America has now more than 2,000 members, and similar societies exist in Great Britian, Italy, Japan, India, and other countries; in spite of the fact that operations research is now considered essential by the Army, Navy, and Air Force, and also by a large fraction of the large corporations in this country, so that millions of dollars a year are being spent for it; in spite of the fact that a dozen universities have given it a place in their curriculum, it must be confessed that there is still some disagreement on the subject of what operations research is, and doubts are being expressed concerning its ultimate future.

I should like here to examine critically just what operations research really is, what it has accomplished, and where it seems to be going, and to do this as objectively as one can who has devoted 15 years to study and research in this field.

Operations research has been defined facetiously as that which operations research workers do. In a sense, I should like to take this definition seriously, for any definition which is not consistent with this would clearly be false. But such a definition is of little value to anyone who is not acquainted with the field and therefore requires recasting into terms intelligible to the general public. I have therefore tried to examine carefully the activities in which those who call themselves operations research workers engage, and thus to find the actual pattern of their work. This has not been a simple undertaking, for these activities range from higher mathematics to philosophical discussions, from antisubmarine tactics to the scheduling of oil refineries. The National Research Council has assigned the Operations Research Society a seat in its Division of Mathematics, but in the universities the courses are most frequently given by engineering departments.

Nevertheless, there is an element common to all these activities. The clue is found in the word *operations*. To understand operations research, it is first necessary to understand this key word. It stems from the military origin of operations research. During World War II groups of scientists, few of whom had any military background or experience, were called up to help the armed services put various new devices and equipment into use. These groups found that doing this required them to study the whole tactical situation in which the devices were to be employed. They found themselves doing research on the operations of fighter aircraft, on the operations of antisubmarine task forces, on landing operations, and thus the term operations research was born.

At the end of the war the term was broadened to include a number of industrial operations. For example, we find research on the operation of warehouses, on the operation of toll bridges and tunnels, on railroad and airline operations, on the operation of direct mail advertising, and all called operations research.

The difficulty at this point is the great broadness of the term operation. Is research on the operation of radio tubes operations research? Is research on surgical operations? The answer to these questions is definitely no. But we must examine why these opera-

[1] The 26th Joseph Henry Lecture of the Philosophical Society of Washington, delivered before the Society on May 3, 1957.

tions are excluded. They are excluded not because of lack of importance or lack of interest but simply because they do not fall into the established pattern of operations research, because they lack certain elements in common with the operations which do fall into this established pattern.

The military and industrial operations we have mentioned have this in common: they all involve a complex system of men and machines. Going a little further, we find that in each case we have a set of machines controlled by a group of men. Operations research has studied the various ways in which this control can be exerted and how the outcome of the operation depends on the control method. It has found certain principles which govern such situations, and is searching for more. To study such things as the operation of a television set would get away from this group control and into a different area.

This brings us near to a definition of operations research, but there remains one more limitation. We have said that operations research is seeking general principles. To the extent that any operation is unique, and completely different from any other operation, to this extent it cannot be governed by general principles. It follows that the search for such principles must be confined to those elements which are common to a number of operations. The success of operations research depends on its ability to discover such similar elements in apparently dissimilar situations. How far this has been possible is a subject to which I shall return. For the present, may I point out that some operations are excluded from operations research because they are unique. For example, the total strategy of the armed forces of the United States at the present moment is such a unique operation. Many parts of the strategy are operations to which operations research can be applied, for they are similar to other operations, but the total is not. Likewise, the operation of the board of directors of, say, the United States Steel Company has unique elements, which prevent its being a suitable subject for operations research, even though there may be many operations within the company which are suitable for such research.

I should thus define operations research as the study of operations in which groups of men control systems of machines, with the object of discovering the principles which govern such operations.

At this point I am faced with a paradox: the definition of operations research to which I have been led seems to exclude a very large part of the work being done at the present time under the title of operations research. The work in question deals for the most part with the sort of operations I have described, but instead of seeking general principles, is concerned with solving specific problems. Much of it consists of the design and construction of control systems. To exclude such work from our domain would be very foolish. Those who consume operations research are interested in, and paying for, practical results in the form of answers to problems and systems designs. If these were not forthcoming, support for operations research would be far more difficult to obtain.

We are concerned here with the age-old distinction between pure and applied science. One way out would be to call the applied side of our subject operations engineering, and in some quarters this has actually been done. In the future I shall use this term when I wish to make the distinction. But we must not lose sight of the historical fact that in the past theory and practice have always gone hand in hand, and a pure science with no applications has never come to much.

On the other hand, it has been proved time and time again that there is nothing as practical as good theory. Would we have the present developments in electronics without Maxwell's equations? Would we have our present-day synthetic drugs and fibers without the theory of chemical valence? If this is the case, isn't the best road to good business management through the study of the principles of business operations, i.e., through operations research? In my opinion, whether the motive is the satisfaction of scientific curiosity or the solution of practical problems the road is the same—the road of research into fundamental principles.

In carrying out such a program, we must make a clear distinction between principles

and techniques. In discussions of operations research we hear very frequent reference to such things as linear programming, dynamic programming, allocation theory, and the like. There are those who regard these subjects as the real essence of operations research. But to me, calling these subjects operations research is the same as identifying physics with the differential equations of physics. Now mathematics is indispensable to physics, and no physicist can get along without a good training in mathematics, but in no sense is physics a branch of mathematics. In a similar way, mathematics is indispensable to operations research, and good operations research (and particularly operations engineering) requires good mathematical training. Just as the mathematical needs of the physicist 100 years ago stimulated mathematical research into differential equations, and just as Riemann's researches into differential geometry provided Einstein with the tools he needed for general relativity, so today we are finding the needs of operations research stimulating research in new branches of mathematics, and operations research workers making use of previously unapplied mathematical developments. This symbiosis is of great importance to both parties, but the distinction between mathematics, with its right to carry any set of assumptions to their logical conclusions, and science, with its obligation to check its assumptions against nature, must still be maintained.

Because many of the mathematical techniques used in operations research are methods of finding maxima and minima, there has arisen a temptation to claim that operations research is the study of the *best* way to control an operation. If real operations were as simple as some of the mathematical models used to describe them, this might be possible. But in reality there are a number of obstacles which have prevented the attainment of this goal. One is a lack of clear understanding of what it is that should be maximized. Superficial criteria like "least cost," "greatest profit," and "greatest return on investment" are all too easy to talk about, but in practice almost impossible to reduce to numerical values.

Take for example the case of inventory control in a store. A relatively simple analysis of a control system will determine the direct dollar costs of carrying stock, the amount of capital which will be required, and the amount of delay the customers will suffer through temporary shortages of stock on hand. As the control system is varied, all three of these factors will vary. What system is "best" depends on some combination of these factors, but there is no agreement on what combination this is. At least at the present time, efforts to find the "best" policy lead only to frustration.

If operations research cannot find the best solution to problems like this, what can it do? First of all, it can describe what will happen under any given control system, without committing anyone as to what is good and what is bad. This is by no means trivial, and in some cases the mere finding of a "feasible solution," a control system which will work at all, is a major victory. In some cases, it can go a step beyond this point: it can eliminate control systems on the grounds that others are better, regardless of the uncertainties of the criterion of success. For example, in the store inventory case, if two systems use the same capital and give the same customer service, the one which has the lower direct cost is surely better than the other. More sophisticated reasoning of this same type frequently reduces the possibilities to a relatively small set of "acceptable solutions."

There is a further difficulty with the finding of "best" solutions. All too frequently when a "best" solution to a problem has been found, someone comes along and finds a still better solution simply by pointing out the existence of a hitherto unsuspected variable. In my experience when a moderately good solution to a problem has been found, it is seldom worthwhile to spend much time trying to convert this into the "best" solution. The time is much better spent in real research in trying to find those variables which have been overlooked, for when these are found much greater improvements become possible than by tinkering with the well-known parameters.

After all this discussion of what operations research is and is not, let us now turn to

its real accomplishments, the areas in which principles have been found and proved by the test of experiment and observation. Time will not permit me to go into any detail, but I would at least like to outline the present state of a number of topics.

Let me begin with what I like to call "congestion theory." This is sometimes known as "waiting-line theory" or "queueing theory," but I object to these terms because in important cases there is no waiting line. The operation under study here is any operation in which service is being given in the face of a fluctuating demand. This includes such varied operations as those of telephone exchanges, barber shops, toll gates, and hospitals. The essence of the problem is to characterize the demand and the service performance, and in terms of these to determine the number of customers lost or delayed because of the congestion which arises. It is familiar to anyone who has been in such a situation that delays occur even when the load on the system is well below its apparent capacity. The theory enables these delays to be calculated in a large variety of important cases.

Closely related to congestion theory is warehousing theory. This differs from congestion theory in that it is possible in a "warehouse" operation to carry goods in inventory, whereas in a barber shop, for example, it is not possible to carry a stock of hair cuts. In the warehouse case, the existence of an inventory makes possible a control of the situation by ordering goods in advance. This is complicated by the fact that a finite lead time is always required, and frequently there are requirements that goods be ordered in full car loads or truck loads. As we have mentioned earlier, the "goodness" of a control system depends on the service provided, the capital required, and on a number of direct costs. All these can now be evaluated and many systems have been successfully designed and placed into operation.

We come next to the theory of transportation systems. Here we are concerned usually with a fleet of ships, railroad cars, trucks, or airplanes, and a complex demand for transportation among a number of terminals. What is usually called "the transportation problem" in linear programming is a very crude first approximation, which neglects the discrete nature of the transportation units and the fluctuations in demand. While a number of features of this theory have been discovered, much research remains to be done before the theory can be called complete.

Communication theory is very closely related to transportation theory. Thanks to Shannon's information theory, it is now possible to measure ratio of flow of information, and the carrying capacity of information flow channels in much the same way as for physical goods. The theory of communication networks is therefore reduced in many respects to the theory of transportation in general, and as the theory of transportation advances, communication theory should advance with it.

Next we come to the theory of production control systems. In a complex manufacturing operation, production control involves a number (frequently a very large number) of operations of the warehousing type, a set of transportation problems, and a communications system, all of which must function together without mutual interference. Typically, some 20,000 different items, ranging from raw materials and purchased parts to finished goods of many sizes and colors, must all be coordinated. In spite of all these difficulties, some of the greatest successes of operations research lie in this area.

Quite a different area of research is that of search theory. This is concerned with the problem of finding things, varying all the way from lost golf balls to enemy submarines and new antibiotics. The theory was quite highly developed during World War II for military purposes, and is just now being declassified for public use.

Finally, as one last example, there is the theory of population dynamics. Taken originally from biology and psychological learning theory, this is now being used to explain the effect of advertising on customer populations, and the determination of the proper distribution of advertising effort. This field is one of the newest, and has still a long way to go.

The areas I have just mentioned are not

the exclusive property of operations research. Just as there is no longer a sharp boundary between physics, chemistry, and biology, so these areas overlap the fields of economics, industrial engineering, cybernetics, and systems analysis. Perhaps the most difficult distinction to make is that between operations research and business research of the type which has been going on for many years. Here I am not even sure that any distinction at all should be made. Business operations are clearly a legitimate subject for business research. Those who have done business research could have done operations research at any time, and in a sense have done just that. Yet it is a fact that operations research has opened new approaches to business problems. It has done this in part because it has introduced new and more powerful mathematical techniques, but if this were all, operations research would deserve little credit. More important has been the fact that operations research has brought to business research the standards and practices of the physical sciences, particularly their insistence on the careful checking of theory against experience and experiment. When this attitude becomes characteristic of all business research, then perhaps the term operations research can be dropped. But until then the distinction must be made.

SHANIDAR SKULL

The skull of a "man before man," who lived in the Near East at least 45,000 years ago, was shown Regents of the Smithsonian Institution at their annual meeting on January 17. It was a cast of the reconstructed skull of a so-called Neanderthaler found last spring in Shanidar Cave in northern Iraq by Dr. Ralph S. Solecki, Smithsonian associate curator of Old World archeology. Dr. T. Dale Stewart, Smithsonian curator of physical anthropology, recently returned from Baghdad where he spent three months reassembling the skull from fragments. The skull is that of a man about 40 years old.

The net result of Dr. Stewart's work was reproduction of the restored skull of a quite unique humanlike creature who lived during the Mousterian cultural period—roughly 45,000 years ago. This was late for Neanderthalers, but about the time the present human race became established. Dr. Stewart went to Baghdad and reconstructed the skull, a job requiring extraordinary knowledge, skill, and precision, at the request of Dr. Nagi al Asil, former foreign minister and now Director General of Antiquities of the Iraq Government. The original skull is being retained in Baghdad. The cast—the only one outside of Iraq—is a gift to the Smithsonian Institution from the Iraq Museum.

The individual, Dr. Stewart says, undoubtedly was a Neanderthaler. This was a race of humanlike creatures whose scant remains have been found scattered through Europe, western Asia, and the Near East. They apparently preceded the true human race, *Homo sapiens*, as it is known today, throughout this region by a few thousand years. They were about the size of present-day man and had essentially all our human features. In general these features were cruder. They were creatures mainly of the last great ice age, presumably cave dwellers, with a flaked-stone culture. They had massive jaws, large faces, protruding brows, and large teeth. Their relation to present-day man is debatable, but it is quite generally doubted whether they were directly ancestral although they lived in the same area where the oldest truly human remains have been found. The first Neanderthal remains were found in Germany almost a century ago. Since then widely scattered specimens have been found. They now are divided into three groups—early Neanderthaler, a form from the last interglacial period in eastern Europe; classic Neanderthaler, the central European cave dweller of the last ice age; and the near eastern Neanderthaler, a late form represented by the present skeleton.

The skull reconstructed by Dr. Stewart, however, shows some quite primitive features considering the date assigned to it. In some respects the face recalls the so-called Rhodesian man of South Africa, sometimes included among the Neanderthalers. The lower jaw also recalls that of the famous Heidelberg man of central Europe, a much more primitive creature of about 100,000 years ago. Whether there ever was any actual connection between Heidelberger and Neanderthaler has been much debated. Dr. Stewart found the parts of the Iraq skull in quite small fragments, which had to be fitted together—a super jigsaw puzzle job made more difficult by the fact that the fellow's skull had been bashed in in several places, presumably in fights with clubs. He apparently had survived all these injuries.

Dr. Stewart's work in Baghdad was a cooperative project of the Iraq Government, the American Philosophical Society and the Smithsonian Institution.

PHYSIOLOGY.—*Observations on the oxygen consumption of young* Australorbis glabratus. ALINA PERLOWAGORA-SZUMLEWICZ[1] and THEODOR VON BRAND, National Institute of Allergy and Infectious Diseases.[2]

(Received October 9, 1957)

The oxygen consumption of developing eggs of *Australorbis glabratus* has been studied from the time of oviposition till the hatching period (Perlowagora-Szumlewicz and von Brand, 1957), and several investigations on the respiration of sexually mature specimens of this species have been published (von Brand et al., 1948, 1953; Edwards et al., 1951). However, no detailed investigation has been made of young specimens; that is, for the interval between hatching and reaching sexual maturity. The present study was designed to close this gap in our knowledge.

MATERIAL AND METHODS

Australorbis glabratus (Venezuelan stock, laboratory maintained since 1947) hatched from the eggs used in our previous study (Perlowagora-Szumlewicz and von Brand, 1957) were isolated during the first 24 hours after hatching into jars containing dechlorinated water and lettuce leaves. Thus a supply of snails of rigorously controlled age was available. The very young snails (freshly hatched to 1 week old) were fairly sensitive to handling, especially during the drying procedure preliminary to weighing. These snails were used therefore only for a single oxygen and weight determination and were then discarded. All other snails, beginning 18 to 21 days after hatching, withstood the necessary manipulations remarkably well and therefore were retested at weekly intervals. The groups established for initial testing were kept separately in beakers between tests and were fed abundantly with lettuce. Powdered calcium carbonate was added at weekly intervals. With increasing size of the specimens, subdivision into smaller groups became necessary.

The oxygen consumption was studied by means of the standard Warburg technique at a temperature of 28°C. Flasks of 5-ml capacity with 1 ml dechlorinated water as medium and flasks of 16 ml capacity with 3 ml water were used, depending on the size of the snails. The experimental period lasted 2 to 3 hours; readings were taken every half hour. The number of specimens per flask varied, depending upon their size. Up to 150 of the smallest and only 1 or 2 of the largest were used. The former were counted under a dissecting microscope prior to the introduction into the Warburg flask which was done with the help of a very fine spatula and a brush. At the end of the experiment the snails were washed out of the flask onto filter paper. They were shifted once or twice to fresh filter paper and allowed to dry for 20 to 30 minutes in air before being weighed on a microbalance to the nearest 0.001 mg. The older snails were dried according to Newton and von Brand (1955) and weighed to the nearest 0.1 mg.

RESULTS AND DISCUSSION

Biological observations.—Because little is known about postembryonic growth of *Australorbis glabratus*, we are describing some of our relevant observations.

Upon plotting the weight of snails as function of age on a double logarithmic scale, two bisecting lines resulted, indicating that the growth characteristics of snails younger than one week are different from those of the older ones (Fig. 1). The data for the latter showed a relatively good fit to a straight line. Thus the total weight, in this range, shows the same growth relationship as the one previously established for the shell in a different, although overlapping size range (Nolan and von Brand, 1954). Whether a straight line, with a different slope, can justifiably be drawn for the youngest snails is dubious because of lack of sufficient points. At any rate, the clearly different growth relationship of the youngest snail groups has a biological foundation. The youngest snails did not feed on lettuce, ignoring the lettuce leaves present in each jar. They can not have subsisted solely on reserves carried over from embryonic life, because they

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did increase in weight. It can be presumed that they fed on microorganisms developing in the jars. These groups of snails will hereinafter be designated as prejuveniles.

The prejuvenile groups are followed by the juvenile groups which are defined as beginning with snails older than 8 days, and ending with specimens reaching sexual maturity. The last groups are comprised of mature snails, that is, snails laying eggs. These two groups fed avidly on lettuce.

It must be emphasized that regularities in growth pattern as shown in Fig. 1 can only be demonstrated when the averages of fairly large numbers are used. While the size of the prejuvenile groups was fairly uniform, pronounced variations occurred among the older groups (Table 1). These variations in growth as related to age were definitely not due to an insufficient food supply; food was present always in surplus. The reasons underlying the variations are obscure and will require special analysis, since several possibilities exist; e.g., unequal food utilization (Kleiber, 1947), deficiencies in endocrine functions, and probably others. Such an investigation would be desirable because size is probably one of the factors determining the onset of sexual maturity in the sense that in our experiments snails weighing less than 50 mg never laid eggs. We determined accurately the age and weight reached by 104 specimens at first oviposition. Their average weight was 109 mg with 58.0 and 208.8 as extremes; their average age varied between 47 and 61 days, i.e., the age varied in much narrower limits than the weight. Because of this observation we consider the age factor as more important than did Pereira and Deslandes (1954) who stated that the period of first oviposition was not related to age but to the growth of snail. It should be emphasized, however, that the age figures given above apply only to our set of conditions; under other conditions the minimal age for first oviposition may be lower. Pereira and Deslandes (1954) noted oviposition by 35-day-old Brazilian *Australorbis glabratus*, Maia Penido et al. (1951) and Perlowagora-Szumlewicz (unpublished) by 32-day-old laboratory-reared Brazilian australorbids. In such cases the minimal weight for oviposition, 50 mg, is reached earlier than in our experiment. On the other hand we had in our material 27 specimens that were unusually slow growers, weighing only between

TABLE 1.—OXYGEN CONSUMPTION OF AUSTRALORBIS GLABRATUS OF VARIOUS AGES.*

Group	Number of experiments	Number of snails in individual experiment	Age of snails days	Weight of single snail mg	mm^3 Oxygen consumed in 1 hr.	
					Per single snail	Per mg
Pre-juveniles						
1	4	113–150	0–1	0.07 ± 0.005 (0.06 – 0.08)	0.11 ± 0.010 (0.08 – 0.12)	1.65 ± 0.11 (1.42 – 1.86)
2	3	115	4–5	0.11 ± 0.007 (0.10 – 0.12)	0.12 ± 0.007 (0.11 – 0.13)	1.12 ± 0.02 (1.09 – 1.16)
3	7	46–100	7–8	0.24 ± 0.022 (0.16 – 0.32)	0.15 ± 0.013 (0.11 – 0.20)	0.56 ± 0.05 (0.32 – 0.68)
Juveniles						
1	10	10–18	18–21	3.17 ± 0.70 (1.21 – 8.10)	1.45 ± 0.38 (0.64 – 4.31)	0.45 ± 0.029 (0.30 – 0.58)
2	13	9–18	26–28	10.6 ± 1.4 (5.6 – 22.7)	4.43 ± 0.35 (2.60 – 6.75)	0.45 ± 0.023 (0.30 – 0.58)
3	7	9–10	33–35	20.5 ± 2.4 (13.0 – 30.3)	9.66 ± 0.89 (6.89 – 13.73)	0.48 ± 0.040 (0.32 – 0.61)
4	13	4–11	39–40	43.4 ± 4.4 (19.0 – 72.3)	12.51 ± 1.39 (5.24 – 21.91)	0.29 ± 0.012 (0.20 – 0.34)
Mature snails						
1	60	1–7	47–61	108.7 ± 4.6 (58.0 – 208.8)	29.3 ± 1.40 (15.7 – 62.0)	0.27 ± 0.005 (0.20 – 0.35)

* In this and the following tables the mean values and, in parentheses, the extremes are presented. The figure following the ± sign is the standard error of the mean.

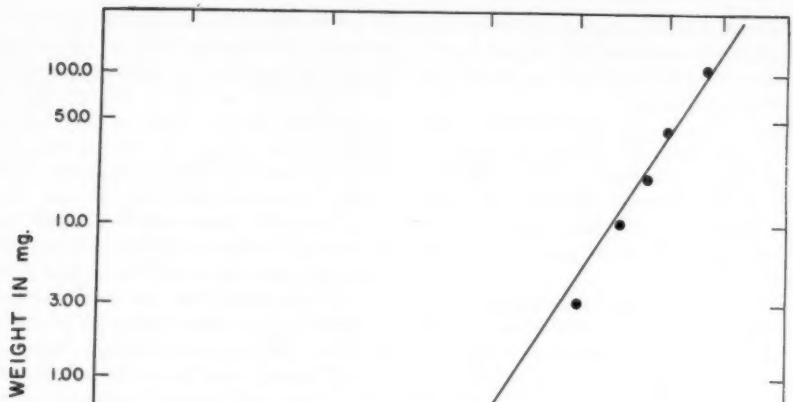

FIG. 1.— Relation between age and weight in growing *Australorbis glabratus*.

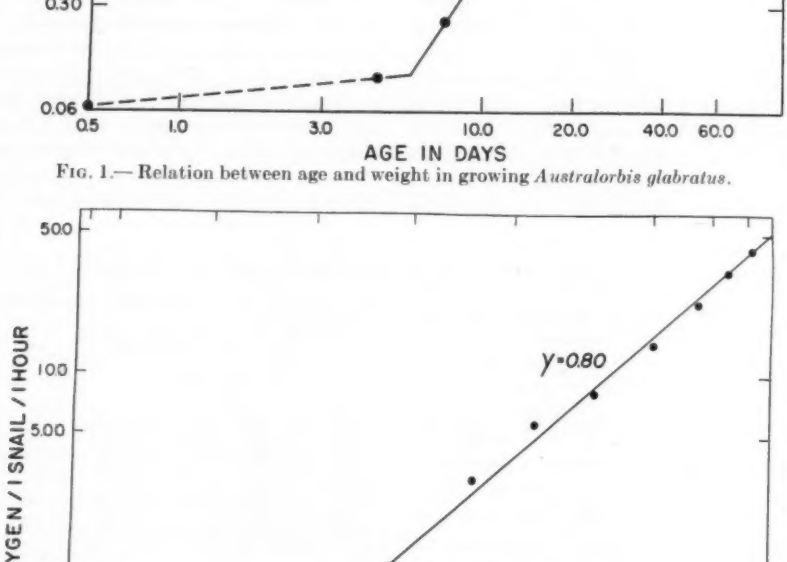

FIG. 2.—Relation between weight and rate of oxygen consumption in growing *Australorbis glabratus*.

24.4 and 44.1 mg when 60 days old. They never laid eggs during the period of observation. It is a matter of conjecture whether they eventually would have reached sexual maturity, or whether they were permanently dwarfed, infantile specimens, as a result, perhaps, of faulty endocrine functions.

Observations of respiratory activity.—As explained above, both the weight and the age of the snails used in the respiration experiments were known; it was therefore possible to correlate the rate of oxygen consumption to both these factors.

As Tables 1 and 2 show, a progressive lowering of the respiratory rates is evident with increasing weight and increasing age, if the rates are calculated on the basis of unit weight. The decrease is greatest in the pre-juvenile groups. Fundamentally, the same trend exists in the other groups, although the decline may be very small if limited size or age differences are considered. The question then arises whether weight or age is primarily responsible for this decline. It is difficult to get incontrovertible evidence on this point, because both factors change in general in the same direction. Our somewhat indirect evidence is as follows: The juvenile groups and the mature group shown in Table 1 had been established purely on the age criterion and therefore each contained both small and large specimens. Each of these groups was now divided into two subgroups (Table 3) one containing the smaller and another one containing the larger snails. In all five groups thus subdivided the respiratory rate of the smaller specimens was higher than that of the larger ones, indicative of a definite trend. Similarly, five groups of the juvenile and mature snails established on the weight criterion (Table 2) contained older and younger specimens. When their average rates were calculated separately, it was found that in two cases the rate of the older specimens was highest, in two other cases that of the younger ones, and in 1 case the rates were equal; that is, a purely random distribution was evident. We are therefore inclined to ascribe to size a more important role in determining metabolic rate than to age, at least in the age range of *Australorbis* studied by us. It is, of course, entirely possible that really senile specimens may behave differently. It should be recalled in this connection that the level of oxidative phosphorylation was reduced in the albumen gland of senile *Lymnaea* (Weinbach, 1956). Planorbid

TABLE 2.—OXYGEN CONSUMPTION OF AUSTRALORBIS GLABRATUS OF VARIOUS SIZES

Group		Number of experiments	Number of snails in individual experiment	Weight of single snail mg	Mm³ oxygen consumed in 1 hour	
					Per single snail	Per mg
Pre-juveniles	1	4	113–150	0.07 ± 0.005 (0.03–0.08)	0.11 ± 0.010 (0.08–0.12)	1.65 ± 0.11 (1.42–1.86)
	2	3	115	0.11 ± 0.007 (0.10–0.12)	0.12 ± 0.007 (0.11–0.13)	1.12 ± 0.02 (1.09–1.16)
	3	7	46–100	0.24 ± 0.022 (0.16–0.32)	0.15 ± 0.013 (0.11–0.20)	0.56 ± 0.05 (0.32–0.68)
Juveniles	1	7	12–15	1.97 ± 0.25 (1.21–3.03)	0.95 ± 0.089 (0.64–1.27)	0.49 ± 0.022 (0.41–0.57)
	2	8	10–18	6.28 ± 0.50 (4.05–8.10)	3.04 ± 0.35 (1.50–4.31)	0.47 ± 0.027 (0.36–0.58)
	3	9	9–15	13.0 ± 0.88 (8.9–16.8)	5.76 ± 0.46 (3.91–8.00)	0.45 ± 0.028 (0.36–0.61)
	4	10	5–11	25.7 ± 1.5 (19.0–33.5)	9.09 ± 0.87 (5.24–13.73)	0.36 ± 0.036 (0.21–0.56)
Mature snails	1*	9	4–5	51.6 ± 4.7 (38.2–60.3)	14.5 ± 0.88 (8.9–16.7)	0.27 ± 0.016 (0.20–0.34)
	2	32	2–7	85.1 ± 1.9 (61.3–105.3)	22.9 ± 0.61 (15.7–29.7)	0.27 ± 0.007 (0.20–0.35)
	3	19	2–3	121.7 ± 1.9 (107.0–137.7)	32.4 ± 1.07 (21.5–38.8)	0.26 ± 0.009 (0.20–0.34)
	4	11	1–3	158.2 ± 6.5 (140.3–208.8)	41.3 ± 3.14 (29.0–62.0)	0.24 ± 0.014 (0.20–0.35)

* This group contains juveniles approaching maturity and mature specimens.

TABLE 3.—ANALYSIS OF RELATIVE IMPORTANCE OF AGE AND SIZE IN DETERMINING THE RESPIRATORY RATE OF AUSTRALORBIS GLABRATUS.*

A. Influence of size (subdivision of age groups shown in Table 1)

Subdivided group	Weight of single snail		Oxygen consumption of heavier snails in per cent of that of lighter ones
	Subdivision a	Subdivision b	
Juvenile 1	1.8	5.2	80
Juvenile 2	7.5	15.3	78
Juvenile 3	14.9	24.8	94
Juvenile 4	28.7	55.9	97
Mature 1	81.6	132.4	96

B. Influence of age (subdivision of weight groups shown in Table 2)

Subdivided group	Age of snails		Oxygen consumption of older snails in percent of that of younger ones
	Subdivision a	Subdivision b	
Juvenile 2	20	27	121
Juvenile 3	27	34	119
Juvenile 4	34	40	64
Mature 1	40	54	100
Mature 2	40	54	93

* For details see text.

snails are reported to reach 2 to 3, occasionally up to 5, years of age[3] (Korschelt, 1922). The 60 days studied by us represent such a small fraction of their life span that a direct age influence can hardly be expected to be demonstrable by the Warburg technique. It is true, however, that we have one observation seemingly in contradiction with the above statement. As mentioned previously, a minority of our snails grew very slowly and did not reach sexual maturity during the time of observation. When the respiratory rate of these older, small specimens was compared with that of younger specimens of approximately equal size, the latter had a distinctly higher rate (Table 4). However, the small, but older, snails must probably be regarded as pathologically retarded specimens. It seems more likely that whatever factor (e.g., endocrine or other) was responsible for their retardation rather than age proper, was responsible for the lowered rate. It certainly would seem desirable to exclude such snails from studies concerned with the normal metabolism. Since they look externally normal, they can be weeded out only when the age is accurately known. In experiments where the greatest obtainable uniformity of material is desirable, both the age and size factors should be considered.

TABLE 4.—OXYGEN CONSUMPTION OF AUSTRALORBIS GLABRATUS OF APPROXIMATELY EQUAL SIZE, BUT DIFFERENT AGE

Number of experiments	Total number of snails	Age of snails days	Weight of single snail mg	Mm³ Oxygen consumed in one hour	
				Per snail single	Per mg
8	77	27–34	21.3 ± 1.9 (15.3–30.3)	9.0 ± 0.95 (6.0–13.7)	0.43 ± 0.033 (0.30–0.56)
5	35	40–41	26.8 ± 2.8 (19.0–33.5)	7.7 ± 1.02 (5.2–10.5)	0.28 ± 0.025 (0.21–0.33)
4	21	61–63	26.0 ± 3.8 (17.4–32.8)	6.7 ± 0.78 (4.6–7.8)	0.26 ± 0.012 (0.24–0.29)

It has been shown previously (von Brand et al., 1948) that a fairly good agreement existed in *Australorbis* between respiratory rate and relative surface, an agreement much better than between weight and rate. The materials used then and now are not completely comparable, because then the age factor was not considered and it is conceivable that some retarded snails had been included; furthermore the experiments of 1948 were done at 30°C, the present ones at 28°C. It is nevertheless of some interest to compare briefly both series in regard to the overlapping size groups. Table 5 shows an excellent agreement between both series which is rather surprising in view of the above differences and the fact that the strain was then newly established in the laboratory but by now is an old laboratory strain. It seems evident that in the size range discussed the oxygen consumption follows more closely, though not completely, the relative surface ($W^{2/3}$) rather than weight.

TABLE 5.—COMPARISON OF 1948 DATA (VON BRAND ET AL.) AND PRESENT DATA ON RESPIRATORY RATE OF AUSTRALORBIS GLABRATUS. (The 1948 data are in italics.)

Weight of individual snail, mg	Mm³ Oxygen 1 snail 1 hour	Relative surface	Ratios of—		
			Weight	Oxygen	Relative surface
13.0	5.8	5.5	1.0	1.0	1.0
14	*5.9*	*5.8*	*1.1*	*1.0*	*1.1*
25.7	9.09	8.7	2.0	1.6	1.6
51.6	14.48	13.9	4.0	2.4	2.5
66	*16.8*	*16.3*	*5.1*	*2.9*	*3.0*
85.1	22.85	19.4	6.5	3.9	3.5
121.7	32.35	24.6	9.3	5.6	4.5
153	*30.3*	*28.6*	*11.7*	*5.2*	*5.2*
158.2	41.3	29.3	12.2	7.1	5.3

When the smaller size groups were included into the above calculation, the deviations from the expected values became more marked. This suggested that the relationship $W^{2/3}$ was not entirely satisfactory to describe the weight/oxygen relations. We therefore analyzed the entire size range used in the present study by the allometric procedure recommended by von Bertalanffy (1951). The respiratory figures are plotted against weight on a double logarithmic scale, resulting usually in a straight line. Calculation of the tangent of the angle formed with the abscissa yields the power to which the body weight must be raised to describe the relationship between body weight and respiration. Upon applying this procedure to our data, it became evident that the pre-juvenile groups behaved differently than the remaining groups (Fig. 2). This is not surprising since in practically all animals studied so far, the relationship between size and oxygen consumption differs in the smallest specimens from that prevailing after the organisms have undergone a certain growth and

[3] The exact life span of *A. glabratus* is unknown. According to unpublished observations by Perlowagora-Szumlewicz only a small percentage survives in captivity longer than 24 months.

possibly again after they reach near maximum size (Zeuthen, 1953). It is evident from Fig. 2 that an identical relationship exists for the juvenile and adult groups; it does not follow weight (y = 1.0) nor surface as calculated by the formula $W^{2/3}$ (y = 0.666), but is actually intermediate. The exponent found by us (y = 0.80) is quite similar to that found by von Bertalanffy (1951) for *Planorbis* (y = 0.75). It must be recognized that one factor exists which introduces a certain amount of uncertainty into the above calculations; the possibility that the metabolically more or less inert shell varies significantly in weight in snails of different size. Indications to this effect have been reported for the larger size range of *Australorbis* (Nolan and von Brand, 1954), but the relation between shell weight and total weight for the smaller size groups has not been established for our strain.[4] It is clear that any error introduced by this factor is reflected in all calculations but it becomes smaller as the exponent to which the weight is raised becomes smaller.

SUMMARY

1. The growth characteristics of *Australorbis* differ during the first week after hatching from those of older specimens.

2. Both size and age seem responsible for onset of sexual maturity.

3. If the whole size range from freshly hatched to sexually mature snails is considered, the respiratory rate decreases materially with increasing size or age if the rate is referred to unit weight, although the decline may be quite small within limited size or age ranges.

4. Size has probably a greater importance than age in determining metabolic rate, at least in the age range studied.

5. While in larger snails a fairly good correlation exists between relative surface and respiratory rate, inclusion of the smaller juveniles leads to discrepancies, indicating that the formula $W^{2/3}$ is not entirely adequate. The exponent 0.80 fits the size range studied much better.

[4] Perlowagora-Szumlewicz (unpublished) considers the age factor as more important in determining the relative shell weight than the size factor.

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To treat your facts with imagination is one thing; to imagine your facts is quite another.—JOHN BURROUGHS.

PALEONTOLOGY.—*A pelycosaur with subsphenoidal teeth from the lower Permian of Oklahoma.*[1]

PETER PAUL VAUGHN, U. S. National Museum.

(Received October 2, 1957)

In his *Osteology of the reptiles* (1956, p. 458), Romer comments on the rarity of teeth on the parasphenoid in the class Reptilia: "While teeth may flourish in reptiles on palatal elements proper, parasphenoid teeth are almost never found in this class—a situation correlated, presumably, with the tendency toward reduction of that bone and particularly of its rostral region. As far as I am aware, teeth on this element have been noted in only a very few instances: on the cultriform process of the millerettid genera, on a platelike development of the bone in the problematical *Lanthanosuchus* and the primitive turtle *Triassochelys*, and on the subsphenoidal area in a pelycosaur as yet undescribed." W. Langston (personal communication, 1957) is currently studying the "pelycosaur as yet undescribed"; he informs me that it is a much larger form, from a different locality and an earlier horizon than the one described in this paper. Peabody (1952, p. 8) has described teeth on the parasphenoid of *Petrolacosaurus*.

In view of this rarity of parasphenoidal teeth in reptiles, a portion, consisting of the combined basisphenoid and parasphenoid, of the braincase of a small pelycosaur from the lower Permian fissure deposits near Fort Sill, Oklahoma is of interest in that it has subsphenoidal teeth. This specimen is of further interest in that it gives us a somewhat clearer picture of the pelycosaurian portion of the fauna of these deposits than we have had; various remains of pelycosaurs are present in the materials collected for the National Museum from the "Fort Sill locality," and Gregory, Peabody, and Price (1956, p. 3) mention small ophiacodont pelycosaurs and medium sized pelycosaurs of uncertain family as part of the fauna.

The portion preserved of this pelycosaur indicates that it is a reptile new to science. *Mycterosaurus*, from the Clyde formation in Texas, is the only other known pelycosaur of comparable size, and its only known horizon is close to that of the form described here. But Romer (1956, p. 681) feels that *Mycterosaurus* is an edaphosaur, and the parasphenoids of edaphosaurs, as far as I can make out from figures given by Romer and Price (1940, pls. 18, 19) are quite unlike that described here. *Mycterosaurus* is, however, a primitive form and may prove to be similar when its braincase is adequately known.

Class REPTILIA
Subclass SYNAPSIDA
Order PELYCOSAURIA

Basicranodon, n. gen.

Diagnosis.—About the size of *Mycterosaurus*. Conical, recurved teeth on the parasphenoid in a concavity between the basipterygoid processes, and on the ventral edge of the parasphenoidal rostrum.

Genotype.—*Basicranodon fortsillensis*, n. sp.

Basicranodon fortsillensis, n. sp.

Diagnosis.—The same as for the genus (the only species).

Type.—U.S.N.M. no. 21859, the greater part of the combined basisphenoid and parasphenoid, lacking the anterior part of the rostrum. Collected in November 1955 by D. H. Dunkle and F. L. Pearce.

Horizon and locality.—From a fissure deposit in Arbuckle limestone at the Dolese Brothers limestone quarry, north of Fort Sill, in sec. 31, T. 4 N., R. 11 W., Comanche County, Okla. This is the locality called the "Fort Sill Locality" by Gregory, Peabody, and Price (1956, p. 3). These fissure deposits are of early Permian age, possibly (*loc. cit.*) of the same horizon as the Arroyo formation, lower Clear Fork of Texas.

Description and discussion.—The basiparasphenoid, U.S.N.M. no. 21859, fits the description of that compound element in other pelycosaurs (Romer and Price, 1940, pp. 74–76) in almost every way—except for the presence of teeth on no. 21859. The basisphenoid and its ventral

[1] Published with the permission of the Secretary of the Smithsonian Institution.

cover, the parasphenoid, are so joined to each other that they are indistinguishable everywhere except in cross-section through the rostrum of the compound element and where the parasphenoid passes posteriorly beyond the posterior border of the basisphenoid to form, presumably, a ventral sheath for the anterior portion of the basioccipital.

In dorsal or ventral view, the specimen, as preserved, lacking the anterior part of the rostrum, has roughly the shape of an isoceles triangle, with the equilateral sides formed largely by the basal tubera. The distance along the base of the triangle, between the lateralmost edges of the two tubera, is 15.5 mm. The distance from the posterior end of either tuber to the posterior end of the rostrum is 17 mm. The distance between the lateralmost tips of the basipterygoid processes is 11.5 mm. In side view, it can be seen that the rostrum meets the body of the basiparasphenoid at a dorsal angle of about 165°.

Comparison of a figure (Romer and Price, 1940, pl. 8) showing the basiparasphenoid in place in *Dimetrodon limbatus* with a figure (*ibid.*, pl. 21) showing a side view of the skull of *Mycterosaurus longiceps* convinces me that the basiparasphenoid of *Mycterosaurus* must have been of very nearly the same size as that of *Basicranodon*. Romer and Price (p. 62) point out that: "Except for the anterior portion of the parasphenoid and the presphenoid, the ossified portions of the [braincase] . . . show little variation in size, despite the great variations found in pelycosaurs in dimensions of the skull as a whole." Nevertheless, the basiparasphenoid of *Basicranodon* is much smaller than that in, say, *Ophiacodon* or *Dimetrodon* (basiparasphenoid of each about twice as large as that in *Basicranodon*, based on plates 3 and 13 of Romer and Price), and we may assume that the whole animal *Basicranodon* was of about the same size as the whole animal *Mycterosaurus*.

In dorsal view, the sella turcica can be seen as a depression in the basisphenoid beginning on a plane through the middle of the basipterygoid processes and extending posteriorly to a plane about midway in the length of the specimen. A low ridge lies along the midline in the posterior part of the sella. Near the anterior end of the sella turcica are a pair of carotid foramina appressed to one another. A groove leads forward from each foramen to the base of the rostrum. This disposition of the dorsal openings of the carotid foramina differs from the situation seen in at least some genera of pelycosaurs (Romer and Price, p. 76) in that the latter show "two unpaired openings . . . one in the floor of the sella, another more anteriorly placed." The lateral walls of the sella are rounded, finished ridges, low anteriorly but rising posteriorly on either side to end at the unfinished posterior rim of the sella. The posterior rim of the sella, with a deep, rounded median notch, shows, as do the corresponding rims in other pelycosaurs (Romer and Price, p. 75), "a broad unfinished surface facing posterodorsally and obviously articulating, through an intervening area of cartilage, with the corresponding antero-ventral face of the proötic ossification in the dorsum sellae." This unfinished surface is thicker on either side of the notch than it is in the midline. The bilateral symmetry of

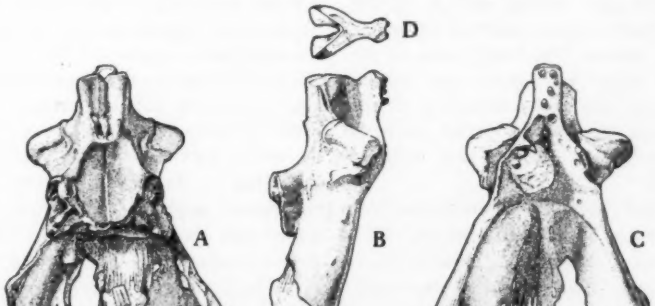

FIG. 1.—*Basicranodon fortsillensis*, n. gen. and sp. (U.S.N.M. no. 21859): Combined basisphenoid and parasphenoid, lacking the anterior part of the rostrum. *A*, dorsal; *B*, lateral; *C*, ventral views. *D*, cross section through rostrum, dorsoventral orientation as in *B*. Approximately × 2.

the posterior rim of the sella in the specimen and the appearance of its surface preclude the possibility of any dorsalward extension of the basisphenoid having been broken away.

The low posterior wall of the sella can hardly be called a dorsum sellae—there are no entire foramina for the abducens nerves—and the broad, unfinished posterodorsal surface indicates that, as is characteristic of pelycosaurs, the dorsum sellae was formed by the proötic. It is this feature that most clearly shows the pelycosaurian nature of *Basicranodon*. According to Romer and Price (p. 68), "The anterior extension [of the proötic] into the dorsum sellae [in pelycosaurs] is unusual. This region is formed in all living reptiles by the basisphenoid; it is formed in the same way in such an advanced cotylosaur as *Captorhinus* . . . ." In 1956 (p. 179), Romer states that "a notable peculiarity [of pelycosaurs] is that, in forms where sutures can be determined, the prominent dorsum sellae is formed by the proötics rather than the basisphenoid." Romer (1956, p. 671) also gives: "Proötic extends forward and medially to form extensive dorsum sellae . . ." as a character for the whole subclass Synapsida, but the horizon of U.S.N.M. no. 21859, from deposits probably equivalent in age to the lower Clear Fork in Texas, rules out assignation to any group of synapsids other than the Pelycosauria.

The basisphenoid seems to terminate posteriorly with the unfinished posterodorsal surface. The parasphenoid, however, extends posteriorly beyond this as a thin plate with many longitudinal grooves on its dorsal surface, which probably, as in other pelycosaurs, served for articulation with the ventral surface of the basioccipital. This thin plate passes on either side into the basal tubera. The bony parts of the tubera, as in other pelycosaurs, are formed entirely by the parasphenoid, although, as Romer and Price suggest (p. 75), the dorsal cavity in each tuber may have been filled with cartilage from the proötic.

In ventral view, the parasphenoid is seen to be broadly concave between the tubera, which diverge from one another at an angle of about 40°. As in other pelycosaurs, each tuber terminates rugosely posteriorly. Anteriorly, just behind the plane of the basipterygoid processes, the two tubera are confluent via a low connecting shelf, which forms an anterior boundary for the (posterior) concavity of the parasphenoid. Passing posteriorly from this shelf, a low, broadly convex ridge, placed slightly to the left, partially subdivides the concavity.

Anterior to the posterior concavity of the parasphenoid, posterior to the rostrum, and between the basipterygoid processes lies a concave area whose ceiling is about two millimeters ventral to the ceiling of the posterior concavity. On the steep side walls of this concave area are teeth, directed ventrally and medially. These teeth are simple, conical, and slightly recurved. They are about 1–1.5 mm in length. The teeth have been lost from the left wall of the specimen, but there are scars on the wall to attest to their former presence there. Four teeth can be seen on the right wall. This being a unique specimen, some of the matrix has been left on the wall to serve as a buttress for these fragile teeth, and it is not possible to say exactly how many teeth were present in life. But, from a comparison of the teeth of the right wall and the scars on the left wall, it seems safe to say that each wall must have held at least five teeth of the greater than 1 mm size, with perhaps smaller teeth around their bases. Scars indicate that small teeth were present on the ceiling of what may be called the "dentigerous concavity," and that an irregular row of small teeth led anteriorly from these to the teeth of the rostrum.

Each basipterygoid process presents two articular faces, an anterior one and a dorsolateral one. These two faces are confluent in a long, broad ridge, which faces anteriorly, laterally and dorsally; the axis of this ridge is mainly a dorsoventral one, but with a forward inclination.

There is a deep ventral trough between each basipterygoid process and the ipsolateral wall of the dentigerous concavity. The posterior half of this trough must have carried the internal carotid artery and the palatine branch of the facial nerve. Midway in the length of the trough, at its vertex, may be seen the ventral opening of the canal for the carotid. Anterior to this, the trough was probably occupied by the palatine artery and the continuation of the nerve; the further course of these structures may be indicated by a longitudinal groove along the lateral surface of the dorsal part of the rostrum on either side. The presence of the dentigerous concavity between the basipterygoid processes, and the consequent effect on other parts of the osteology

in this area, including the mode of entrance of the internal carotid artery, are points of difference from other described pelycosaurs. In other pelycosaurs there is (Romer and Price, p. 75) between the basipterygoid processes "a narrow valley. Grooves converge forward and downward into this valley from the sides of the bone, presumably indicating the course of the palatine nerve and internal carotid . . . All well-preserved specimens . . . show a pair of foramina [for the internal carotid arteries] entering the bone from below between the basipterygoid processes."

Only the posterior three millimeters of the rostrum are preserved. The ventral surface of the rostrum in this region is about 1.5 mm wide. This surface bears four large teeth, blunter than those farther back, and about one-half as long; and one smaller tooth. The two anteriormost teeth seem to be almost paired. The large tooth behind these is on the left side with a tooth scar alongside it. The succeeding tooth is on the right with a tooth scar to its left. The small tooth is on the left just behind the anteriormost pair. An irregular, but apparently single-file, row of tooth scars connects the rostral row of teeth with the teeth on the ceiling of the dentigerous concavity.

The cross-sectional view of the rostrum afforded by the breaking away of the anterior part clearly shows the basisphenoid in this region in the shape of a V clasped in and ventrally covered by the arms of the Y-shaped rostral portion of the parasphenoid. The stem of the Y is widened ventrally to form the dentigerous portion of the rostrum. The groove of the V, which must have held the sphenethmoid, terminates posteriorly about 1.5 mm anterior to the dorsal openings of the carotid foramina.

There are other pelycosaurian elements in the National Museum collection from the Fort Sill locality, notably an ilium with a build like that of a sphenacodontid, from a pelycosaur about the size of *Mycterosaurus*—and, therefore, about the size of *Basicranodon*—but assignation to *Basicranodon* seems unwarranted.

The determination of the subordinal position of *Basicranodon* is difficult. Romer (1956, p. 675) gives: "Fenestrae ovales more widely separated than in other suborders, as are the basicranial tubera," as part of his diagnosis of the Ophiacodontia. The tubera are widely separated in *Basicranodon*. Inspection of the figure of *Ophiacodon uniformis* (pl. 3) given by Romer and Price indicates some similarity in that *Ophiacodon* has another concavity, roughly comparable to the dentigerous concavity in *Basicranodon*, anterior to a deeper parasphenoidal concavity; these two concavities are separated, as in *Basicranodon*, by a distinct "step." *Basicranodon* may be an ophiacodont.

Acknowledgment.—The drawings illustrating this paper were made by Lawrence B. Isham.

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It is no shame for a man to learn that which he knoweth not, whatever be his age.—ISOCRATES.

ZOOLOGY.—Sarsiella, tricostata *a new ostracod from San Francisco Bay* (*Myodocopa: Cypridinidae*).

MEREDITH L. JONES, University of California, Berkeley.[1]

(Communicated by Fenner A. Chace, Jr.)

(Received August 23, 1957)

In the course of sampling the benthic fauna off Point Richmond, San Francisco Bay, Calif. (Jones, 1954), a series of three types of ostracods were encountered. These animals, which provide the basis for the following description, were collected at depths of 2 to 30 feet below mean lower low water and were most common at depths of less than 12 feet. At first, because of the press of the program at hand, and owing to the scanty knowledge of Pacific coast members of this group, they were referred to as Ostracods "A," "B," and "C." Subsequent investigation indicated that all three were of the genus *Sarsiella* Norman, 1869.

At the time of Müller's work (1912) some 19 species of *Sarsiella* were recognized, and since then only one additional species has been described (*S. misakiensis* Kajayama 1912). Of the known species, only two (*S. americana* Cushman, 1906, and *S. zostericola* Cushman, 1906) possess shells bearing three ridges that converge near the shell center, a characteristic that is constant in the specimens from Point Richmond. However, although the gross outline of Ostracod "A" was almost identical to that of *S. americana*, the shell ribs of Ostracod "A" were oriented differently, and the dorsal margin of the shell (irregularly notched in *S. americana*) was smooth. On the other hand, Ostracods "B" and "C" bore a superficial resemblance to the female and male of *S. zostericola*, respectively.

As will be seen later, there are other differences that help differentiate between Cushman's two species of *Sarsiella* and the present form and that justify the erection of a new species, *Sarsiella tricostata*; to include Ostracod "A," the mature female, Ostracod "C," the mature male, and Ostracod "B," juvenile forms of undeterminable sex. The specific name is based on the obvious ribbing of the shell surface.

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Suborder MYODOCOPA

Family CYPRIDINIDAE

Genus **Sarsiella** Norman, 1869

Sarsiella tricostata, n. sp.

Figs. 1, A-P; 2

Ostracod "A" (female) Jones, 1954.
Ostracod "C" (male) Jones, 1954.
Ostracod "B" (juvenile) Jones, 1954.

Since three morphologically distinct forms were encountered, they will be described separately.

MATURE FEMALE (Fig. 1, A-E)

The shell of the mature female (Fig. 1 A) is subovate, with the posteroventral margin drawn into a broad, bluntly pointed process. The ventral margin is entire, and fine setae are inserted along the margin from the anterodorsal area continuously to and around the posterior process. The main surface of the shell is slightly raised from the marginal area, except near the posteroventral process. A secondary margin is thus formed from which some setae originate in the ventral region. Fine hairs are scattered over the main surface of the shell, which is divided into three fields by three ridges extending from or near the secondary margin to a point of junction, slightly anterior and ventral to the midpoint of the shell. The areas delimited by the ridges vary in size, the largest being dorsal, the smallest anteroventral, and the medium posteroventral. A fourth field in the posterior area lies in the transverse plane and extends from the margin to an indentation of the raised surface of the shell. There is a light calcification rendering the shell translucent, although occasionally it may be quite transparent. The length of the shell is 1.2 mm, its height 1.0 mm.

The last (fifth) joint of the antennules (Fig. 1 B) bears five to seven heavy, annulated setae, and the fourth joint bears one or two annulated setae. The third joint bears three setae, two of which are annulated, at the posterior distal angle, and two more nonannulated setae on the anterior margin, one proximal, and one distal. In addition,

a fine seta may be present on the posterior margin of the third joint.

The natatory (primary) branch of the antenna is composed of 10 joints, the base of which is shown in Fig. 1 C(*cf.* Fig. 1 N). The first may bear a single fine seta on the anterior margin, the next eight joints bear a single heavy, annulated seta on each, and the terminal joint bears a pair of heavy annulated setae. The secondary branch of the antenna is a rudimentary protuberance which bears a single distal spine and a pair of heavier proximal spines.

The mandible (Fig. 1 D) usually bears short spines at the anterior distal angle of the second, third, and fourth joints, and four or five spines on the posterior margin of the second joint. In addition, the last three joints bear the large spines characteristic of the genus.

The caudal lamina (Fig. 1 E) has five heavy spines in each plate, decreasing in size dorsally. The shortest spine bears only fine hairs, but the other four all bear short spines proximally, which grade into fine hairs, distally. In addition, there are fringes of fine hairs on the posterior margins of the laminae.

MALE (Fig. 1, F-K)

The shell of the male of *Sarsiella tricostata* (Fig. 1 F) is strikingly similar to that of the male of *S. zostericola*. The dorsal margin is broadly rounded. The ventral margin is nearly straight and gives way to the antennal sinus anteriorly, while the posterior margin is truncated, rounds gently into the dorsal margin, and, ventrally, forms nearly a right angle. As in the case of the female, the main surface of the shell is raised from the level of the margin and is divided into three fields by ridges. The fourth field is essentially lacking. The surface of the shell is strewn with fine hairs, and fine marginal setae extend from the anterior area, along the ventral margin, to the posterior area. The length of the shell is 1.0 mm, its height 0.7 mm.

The third joint of the antennules (Fig. 1 G) possesses a cluster of long filamentous setae with an accompanying heavy annulated seta. On the anterior margin there are two setae, as in the female. The fourth joint bears two setae, and the fifth bears six heavily annulated setae.

The primary branch of the antenna (Fig. 1 H) is similar to that of the female, but the secondary branch is quite different. It is composed of three joints; the first bears two spines, the second, three heavy spines, and the third is recurved onto the three spines of the second. In addition, the tip of the terminal joint appears to be equipped with a ridged area which may function, along with the spines of the second joint, as a part of a clasping apparatus.

The second joint of the mandible (Fig. 1 I) bears three main annulated spines. In addition there may be two to four smaller annulated spines at the base of the most proximal of the main spines. On the lateral distal margin there are three fine annulated setae, one short and two long. The third, fourth, and fifth joints bear large clawlike setae and may also have a small spine at the distal lateral angle. At the base of the large claw of the fifth joint there may be a second small spine.

The caudal lamina (Fig. 1 J) is similar to that of the female except that the fringe of setae on the posterior margin is replaced by a few short bristles.

The copulatory organ (Fig. 1 K) is similar to that of the male of *S. zostericola* in that each half is composed of a large blunt hook and a smaller one with a pair of spines distal and another pair proximal to the smaller hook. In *S. tricostata*, however, there are no spines near the base of the organ.

JUVENILES (Fig. 1, L-P)

As stated above, the shell of juvenile *S. tricostata* (Fig. 1 L) is quite similar to the outline of the female of *S. zostericola*. It is similar to the shells of adult *S. tricostata*; the fourth area of the shell surface is obvious, as in the adult female, and the centrally oriented ribs delimit the other three fields. Marginal hairs extend from the anterodorsal margin, ventrally, to the posterior dorsal area. A posteroventral process similar to that of the adult female is also present.

The antennules (Fig. 1 M) are also similar to those of the adult female, and differ only in having five to seven terminal annulated setae and one large annulated seta and several small ones on the posterior margin.

The structure of the secondary antennal branch (Fig. 1 N) is quite variable in the juvenile forms of *S. tricostata*. Indeed it is possible to trace a line of development of this appendage (Fig. 2). The series illustrated was arranged according to two criteria. First, it was felt that the length of the first joint of the primary antennal branch was indicative of relative age. Second,

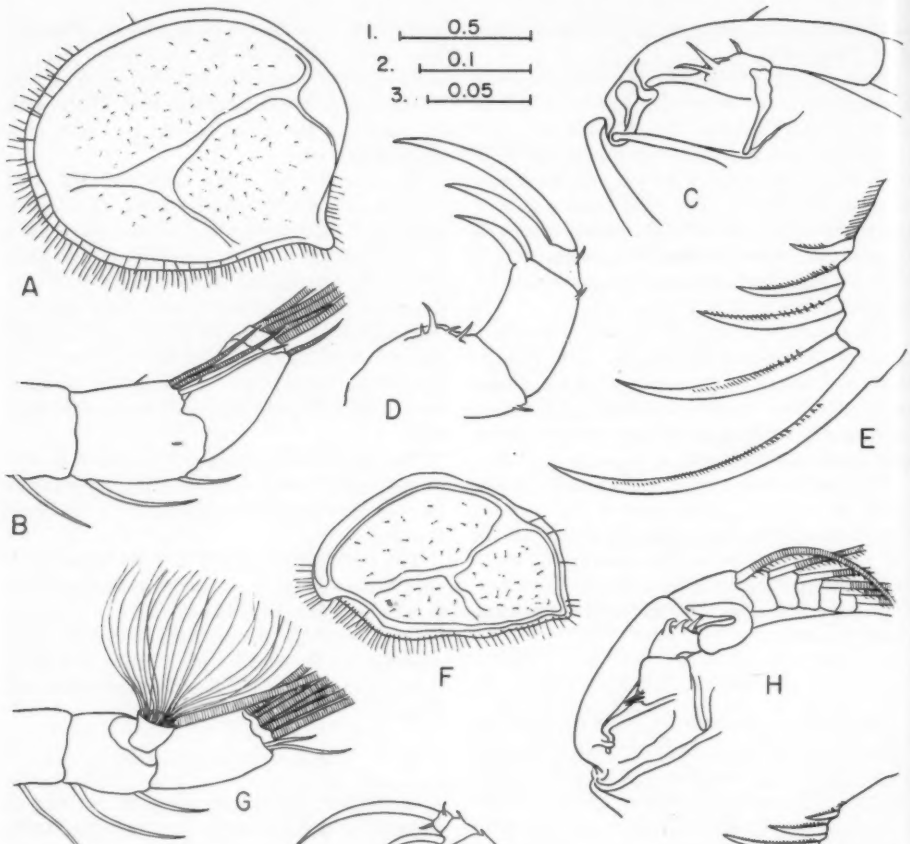

FIG. 1.—(For explanation, see opposite page).

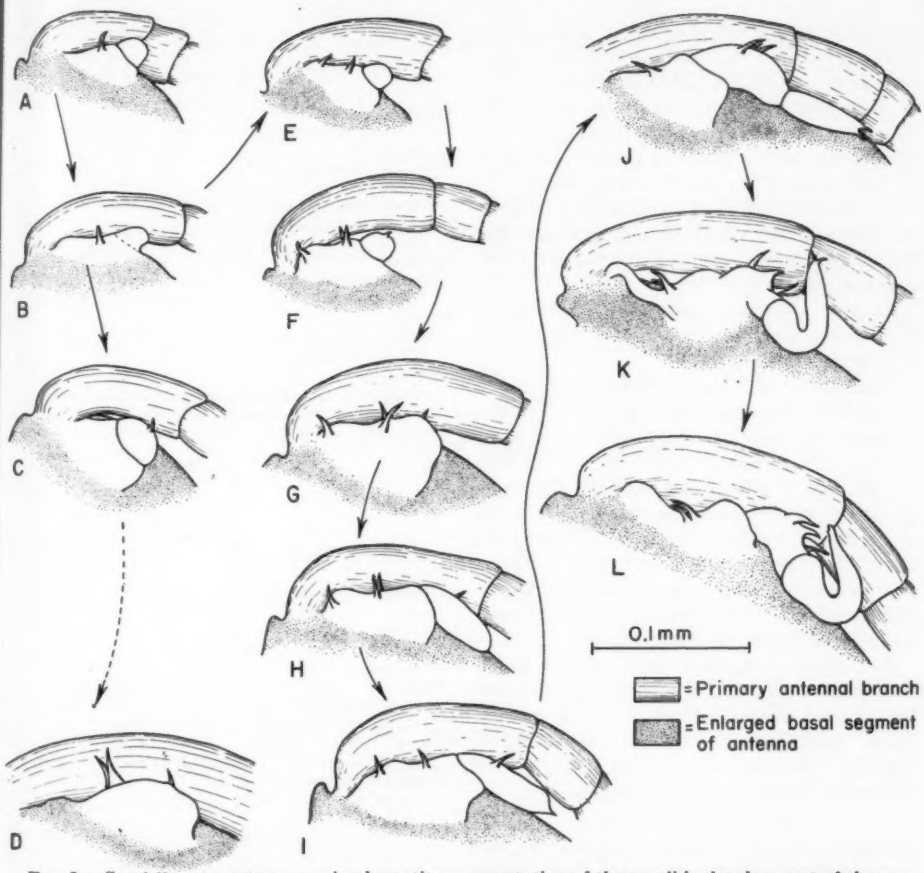

FIG. 2.—*Sarsiella tricostata* n. sp.: A schematic representation of the possible development of the second antennal branch, prepared from *camera lucida* drawings. 2 D shows the condition in the adult female, and 2 K and 2 L that in adult males. The remaining figures are those of juveniles.

it was assumed that once a spine pattern had been established, it would probably not be disrupted. The only nonjuvenile forms shown in Fig. 2 are "D" (adult female) and "K" and "L" (adult males). It would seem that, during the development of the secondary antennal branch in female *S. tricostata*, there is an early fusion of two joints to form the rudimentary branch with a single distal spine and two proximal spines. In the male there is an early fusion and, in later molts, the redevelopment of the second and the appearance of a third joint. No claim is made that this series is complete, and it is admitted that the appearance and disappearance of certain

FIG. 1.—*Sarsiella tricostata*, n. sp.: A–E, adult female; F–K, adult male; L–P, juvenile. A, lateral view of left shell of female; B, medial view of right antennule; C, medial view of left antenna; D, medial view of right mandible; E, lateral view of right caudal lamina; F, lateral view of left shell of male; G, medial view of right antennule; H, medial view of left antenna; I, medial view of right mandible; J, lateral view of right caudal lamina; K, lateral view of left half of copulatory organ; L, lateral view of left shell of juvenile; M, medial view of right antennule; N, medial view of left antenna; O, medial view of right mandible; P, lateral view of right caudal lamina. (Scale 1 at the top of the plate applies to figures of the shells, 1 A, 1 F, and 1 L; scale 3 applies to the figure of the male copulatory organ, 1 K; and scale 2 applies to all of the remaining figures.)

spines may be due to difficulties in observation. However, it is felt that the general trend of development can be made out in this figure.

The mandibles of the juvenile form (Fig. 1 O) are similar to those of the adult female, but with fewer spines on the posterior margin (3–5) and no small spines at the distal anterior angles.

The spines of the caudal lamina (Fig. 1 P) are also similar to those of the female adult, but the two smallest spines are devoid of either short spines or fine hairs.

Since *S. tricostata* most closely resembles *S. zostericola* a table comparing the two species is presented opposite.

Distribution of type material.—The adult female of *Sarsiella tricostata* is designated as the holotype, and the male adult is designated as an allotype. The holotype (U.S.N.M. no. 100903) the allotype (U.S.N.M. no. 100904), and paratypes (15 females, 4 males, and 15 juveniles, U.S.N.M. no. 100905) have been deposited with the U. S. National Museum. In addition, paratypes have also been deposited with the Museum of Paleontology, University of California, Berkeley, and the British Museum, London.

The author is indebted to Dr. Cadet Hand, Department of Zoology, University of California, for his kind advice and criticism, and to Mrs. Emily Reid, illustrator for the Department of Zoology, University of California, Berkeley, for the figures illustrating this description.

	♀	
	S. zostericola	*S. tricostata*
Antennules:		
Number of setae on fifth joint	5*	6(5–7)**
Number of setae on fourth joint	3*	1–2
Number of setae on posterior distal angle of third joint	2*	3
Antennae:		
Setae on rudimentary secondary branch	1 distal 1 proximal	1 distal 2 proximal
Mandible:		
Number of spines on posterior margin, second joint	7*	4–5

* Number is based on text figure, not on the text itself.

** Figures within parentheses represent ranges, figures outside represent mean or the most common number.

	♂	
	S. zostericola	*S. tricostata*
Antennules:		
Number of setae on fourth joint	3	2(1–2)
Antennae:		
Number of joints in secondary branch	4	3
Mandibles:		
Number of spines on posterior margin, second joint	3	5(5–7)
Number of setae on anterior margin, second joint	2 long 2 short	2 long 1 short
Copulatory organs:		
Number of setae on upper end	2	0

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Nature never says one thing and science another.—JUVENAL.

ZOOLOGY.—*Description of a new species of* Cossura *(Annelida: Polychaeta) from the Mississippi Delta.*[1] DONALD J. REISH, University of Southern California. (Communicated by Fenner A. Chace, Jr.)

(Received December 4, 1957)

While identifying polychaetous annelids from the Mississippi Delta, I discovered a new species of the cirratulid genus *Cossura* Webster and Benedict. The material was collected by Robert H. Parker, with a size 1 Hayward orange-peel bucket, of the Scripps Institution of Oceanography. The results of the quantitative survey, including a list of the polychaetes collected, have been published (Parker, 1956).

The genus *Cossura*, known for only three previous species, has attracted considerable interest in recent years. This is largely the result of increased emphasis upon quantitative studies coupled with refinement of handling techniques once the samples have been taken. *Cossura longocirrata* was described by Webster and Benedict (1887) for specimens collected at Eastport, Maine. This species was subsequently reported from Denmark (Eliason, 1920; Thulin, 1921), North Atlantic (Wesenberg-Lund, 1950),

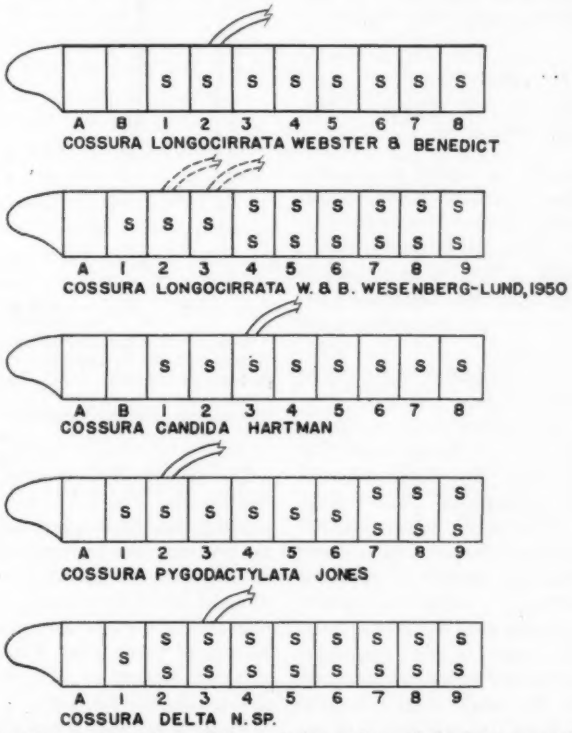
A B 1 2 3 4 5 6 7 8
COSSURA LONGOCIRRATA WEBSTER & BENEDICT
A 1 2 3 4 5 6 7 8 9
COSSURA LONGOCIRRATA W. & B. WESENBERG-LUND, 1950
A B 1 2 3 4 5 6 7 8
COSSURA CANDIDA HARTMAN
A 1 2 3 4 5 6 7 8 9
COSSURA PYGODACTYLATA JONES
A 1 2 3 4 5 6 7 8 9
COSSURA DELTA N. SP.

FIG. 1.—Diagrammatic representation of the anterior regions of the known species of *Cossura*. The number of asetigerous segments posterior to the prostomium is indicated by the letters A and B. The setigerous segment number is indicated by the numerals. The single letter S within a segment indicates that the setae of the notopodium and neuropodium are continuous. Two letter S's indicate separation of the setae of these two lobes.

[1] Contribution no. 210 from the Allan Hancock Foundation, University of Southern California.

and British Columbia (Berkeley and Berkeley, 1956). *Cossura candida* was recently described by Hartman (1955b) from southern California. Included under this species are the reports from San Pedro Basin (Hartman, 1955a, as *Cossura* sp.), Los Angeles—Long Beach Harbors (Anon., 1952, as *Cossura longicirrata* [sic]; Reish, 1955, as *Cossura* sp.) and Alamitos Bay (Reish and Winter, 1954, as *Cossura longicirrata* [sic]). More recently Jones (1956) described *Cossura pygodactylata* from San Francisco Bay.

Family CIRRATULIDAE

Genus **Cossura** Webster and Benedict, 1887

Cossura delta, n. sp.

Many individuals, all incomplete posteriorly, come from the Pass a Loutre region of the Mississippi River Delta, Gulf of Mexico (Parker, 1956). The holotype measures 66 mm in length and 0.5 mm in width. A total of 25 setigerous segments are present. The ten paratypes have from 22 to 34 setigerous segments and measure from 5 to 10 mm in length.

Anterior end.—The prostomium is conical in shape, has two nuchal organs, but lacks eyes. The proboscis is everted in some of the specimens; the base bears from 15 to 20 digitate lobes. The peristomium lacks setae. The first setigerous segment follows the peristomium. *Cossura delta*, as the other species in the genus, lacks parapodia; the setae originate directly from the lateral body wall. The first setigerous segment is biramous with the setae forming a continuous lateral series (Fig. 1). Beginning with the second setigerous segment, the setae of the notopodial region and the neuropodial region are distinctly separated (Fig. 1). The single long, cylindrical tentacle originates from the middorsum of the third setigerous segment. It measures 8 mm in the holotype, but it was undoubtably broken during the process of collecting.

Setae.—There are two kinds of setae in *Cossura delta*. One type is a simple capillary which is armed with spines along its outer edge (Fig. 2, A). They are found in both the notopodium and the neuropodium. They number 7 to 9 per lobe in the notopodium (Fig. 2, A) and are directed posteriorly. The capillaries are more slender in the neuropodium (Fig. 2, B). These setae, which number 4 to 8 per lobe, are directed posteriorly.

FIG. 2.—A, Capillary seta from the notopodium of segment 10; B, capillary seta from the neuropodium of segment 10; C, limbate seta from the neuropodium of segment 10; D, limbate seta from the neuropodium of segment 15.

The second kind of setae is simple curved limbate ones (Fig. 2, C) which are limited to the anterior neuropodial segments. They begin at the first setigerous segment, reach their maximum development at segments 7 to 12, and gradually diminish in size from segments 18 to 25 (Fig. 2, C and D). Fine spines are present along the outer margin of these setae. Generally four limbate setae are present in each lobe. These setae are directed slightly forward.

Posterior end.—It is unknown in *Cossura delta* since all specimens were incomplete posteriorly. The posterior end of the other three species are similar. The setae are as in the anterior segments, and the pygidium bears three long anal cirri. In addition, *C. pygodactylata* is characterized by possessing 6 to 10 digitate lobes on either side of the anus.

Discussion.—*Cossura delta* differs from the other known species of the genus in possessing curved limbate setae in the anterior neuropodia (Fig. 2, C and D), and the separation of the notopodial and neuropodial setae at the second

setigerous segment (Fig. 1). This species comes nearest to *C. longocirrata* as reported by Wesenberg-Lund (1950) and Berkeley and Berkeley (1956). These two species are characterized by having one setigerous segment posterior to the prostomium and the tentacle originating from the dorsum of the third setigerous segment (sometimes second in *C. longocirrata* as stated by Wesenberg-Lund, 1950) (Fig. 1). The anterior ends of the four species of the genus are diagrammatically represented in Fig. 1. Since some differences exist between the reports of *C. longocirrata* by Webster and Benedict (1887) and that by Wesenberg-Lund (1950) and Berkeley and Berkeley (1956), diagrams are included for each.

Type material.—The holotype (U.S.N.M. no. 28706) and 5 paratypes (U.S.N.M. no 28707) have been deposited in the U. S. National Museum. Five paratypes have been placed in the polychaete collections of the Allan Hancock Foundation. University of Southern California.

Type locality.—Station number 328 (Parker, 1956), off Pass A'Loutre region of the Mississippi River Delta. It was collected in shallow depths in clayey sediments.

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I envy no man that knows more than myself but pity them that know less.—SIR THOMAS BROWNE.

ZOOLOGY.—*A survey of inequivalve pelecypods.* DAVID NICOL, U. S. National Museum.

(Received November 22, 1957)

In their brief paper on discordant pelecypods Newell and Merchant (1939, p. 176) make the following statement: "Evidently discordancy is not prevalent in modern forms, for there is scarcely any mention of the phenomenon in the literature that we have examined." These authors limit the meaning of discordancy to a difference in height and length measurements of the two valves, or, in their term, the "diameter" of the valves. Although they are correct in implying that little has been written on the subject of discordant valves in modern pelecypods, except in conjunction with general morphologic descriptions of pelecypod taxa, they err in inferring that discordancy is an uncommon phenomenon among living representatives of this class of mollusks.

On page 177, Newell and Merchant make the following statement: "However, there are many modern forms with markedly inequivalve convexity in which the valve margins are perfectly accordant." This certainly is not the case. Most examples of marked inequality of the valve convexities also show some discordancy. Moreover, in some cucullaeids and corbulids, for example, some discordancy is present accompanied by little difference in the convexity of the two valves. Actually, inequal valves of pelecypods may vary as to convesity as well as diameter, and these two variations are sometimes accompanied by a discrepancy in the ornamentation on the two valves of a specimen.

This paper will deal with inequivalve pelecypods in the broader sense because these variations are commonly interrelated morphologically. I have listed in tabular form suborders, superfamilies, families, and genera of inequivalve pelecypods, most of which are also discordant. The list is not to be considered exhaustive, and only a few fossil groups are mentioned. However, from the list alone, it should be quite clear that discordant pelecypods are far from rare.

Many families and genera of normally equivalve pelecypods are, on rare occasions, represented by individuals which, through some freak of growth, whether inspired by environment or by some genetic peculiarity or both, have developed inequal valves. These odd specimens will be ignored for the present discussion. Some of the more unusual occurrences of inequivalve pelecypods are covered by Lamy (1930).

Even in families and genera whose representatives are considered normally equivalve, the two valves usually do not coincide perfectly with each other. A case in point is seen in the Astartidae (Nicol, 1955, p. 155) where in the lunular area the margin of the right valve slightly overlaps the left, whereas in the escutcheonal area the left valve slightly overlaps the right. Cotton and Godfrey (1938, p. 169) point out the same phenomenon in the genus *Cuna* (Crassatellidae). The right valves of some donacids slightly overlap the left valves along the dorsal margin. More examples of this morphologic characteristic could be included. This is apparently a supplementary locking device to keep the valves from twisting, and for our present discussion this phenomenon, with but one possible exception, will not be included in the inequivalve pelecypods.

In this discussion of inequivalve pelecypods I shall begin with the most primitive taxa and conclude with the most specialized ones.

Pelecypods having protobranch ctenidia are structurally the most primitive living members of the class. It is interesting to note that none of them is included in the list of inequivalve forms. Could this mean that the first pelecypods (late Cambrian or early Ordovician) all were equivalve? It may be that the inequivalve characteristic did not appear with the most ancient pelecypods but was a secondary morphologic feature which manifested itself a short time later.

Although the majority of Ordovician pelecypods are equivalve, there are a few genera, most of them having small numbers

of species, which are inequivalve. One such genus is *Aristerella*. It is found in Middle Ordovician strata and is the oldest inequivalve pelecypod I have seen. The exact systematic position of the genus is in doubt; it has been placed among the mytilaceans by most paleontologists and in the pteriaceans by others. Ulrich (1897, p. 524), the original describer, and subsequent workers have reported *Aristerella* as having the right valve larger than the left. This genus has a somewhat pteroid shape, and, if the obliquity of the shell is prosocline, the right valve is the more convex on most, but not all, the specimens examined. (The one or two exceptions are small internal casts and may be examples of distortion.) Two large specimens from Estonia, labeled *Aristerella* in the collection of the U. S. National Museum, are strikingly inequivalve, the right valves being larger than the left. In this respect *Aristerella* is similar to *Heikea* from the late Ordovician of Sweden. Isberg (1934, pp. 273–315, 388–389) describes *Heikea* and allocates the genus to the family Cyrtodontidae, which some systematists have placed among the prionodonts probably for want of a more accurate assignment. Although the specimens which Isberg figures are not markedly inequivalve, he asserts that in most species of *Heikea* the right valves are larger than the left.

Another early Paleozoic group which is inequivalve is the family Antipleuridae. This family of paleoconchs is restricted to the late Silurian and early Devonian and is represented by such genera as *Antipleura*, *Dalila*, and *Dualina*. According to Lamy (1930, p. 130, footnote) either left or right valves may be larger. Figured specimens of these genera show a great difference in the sizes of the valves.

From late Ordovician onward throughout the remainder of the Paleozoic, because of the abundance of pteriaceans and pectinaceans, most of the inequivalve pelecypods have their left valves larger than their right valves. Besides the exceptions to this rule already mentioned, *Vertumnia*, a pterinopectinoid genus restricted to the Devonian; many species of *Cypricardinia*; and the obscure genus *Dexiobia* all have right valves larger than left valves. *Cypricardinia* ranges from Silurian through Mississippian, and *Dexiobia* is confined to the latter Period.

I have not attempted to list all the Paleozoic pelecypods having larger left valves than right. Furthermore, I have listed none in which the inequivalve characteristic is doubtful, whether left or right. Some paleontologists assert that certain Paleozoic genera are inequivalve whereas others do not mention this characteristic in their generic or familial descriptions. The implied discrepancy may be due to oversight on the part of some workers or to distorted specimens in the Paleozoic collections of others.

Bivalves with filibranch ctenidia—i.e., those whose morphological development is second most primitive—constitute the largest group of inequivalve pelecypods from the standpoint of percentage. Most members of this order have well-developed byssal attachments or are attached by their shells directly to the substrate or, if free-living, have descended from ancestors which had some form of attachment. Apparently their pleurothetic mode of life is related to the inequal development of their valves. Furthermore, among the filibranchs, the inequivalve condition is most consistent as well as prevalent. In most families, the inequivalve species always have their left valves larger, but in a few families the inequivalve representatives always have their right valves larger. There are few exceptions, and this consistency can be considered, along with other morphological characters, as an indication of phyletic relationship.

There are several groups of filibranchs which consistently are either equivalve or, if inequivalve, have the left valves larger than the right. The Pteriacea are probably the most ancient and among the most prominent of this group. The Leiopteriidae and Pterineidae commonly have inequal valves, and the left valves are always the larger. (See La Rocque, 1950). A striking example of this inequivalve condition is seen in the genus *Cornellites*. These pteriaceans, which are among the most ancient inequivalve pelecypods, are like the modern species, and it is quite significant that this

large superfamily, which first appeared in the Ordovician Period, has consistently throughout its long history possessed the same inequivalve characteristic—the left valves invariably being the larger. Other fossil pteriaceans which are inequivalve include the genus *Buchia* and the family Myalinidae; both have representatives with their left valves larger than the right. (I must add that I would include the Myalinidae with the Pteriacea rather than the Mytilacea on the bases of the inequivalve condition, the shape of the shell, and the appearance of the ligamental area, despite Newell's assertion in 1942.) Many living species of the Pteriidae are inequivalve, the left valves always being larger than the right.

The mytilaceans seem to be a consistently equivalve group with but few exceptions. *Myoforceps aristata* has prolonged posterior ends of the valves which tend to cross over each other. In some specimens the right and in others the left valves are the larger and more prolonged. Other exceptions are *Stavelia torta* and *Stavelia horrida*, large shells found in the Philippines and Queensland. In these species either right or left valves may be larger. *Fluviolanatus subtorta* is another inequivalve mytilid found in Australian waters.

Another group of filibranchs is the prionodonts, which first appear in the Devonian. The Cucullaeidae and their allies constitute a large suborder, and among its representatives are some species which are inequivalve, the left valves always being the larger and overlapping the right valves along the ventral border. Sometimes this discordancy is accompanied by a striking discrepancy in the ornamentation on the two valves. Some Paleozoic representatives of the Prionodonta and some Paleozoic Pteriacea are remarkably similar in outline and hinge characters, and the fact that both groups have similar inequivalve conditions leads to the possible inference that these two great groups are closely related.

In addition to the pteriaceans and prionodonts, a third and related group having inequivalve species is the Isognomonacea, which includes fossil groups like Cox's Bakevelliidae and the well-known genus *Inoceramus*. Besides the tendency to have inequal valves, the left valves being consistently the larger, these three large groups have other morphologic similarities to link them. The modern isognomonids are not so conspicuously inequivalve as their fossil ancestors, but in an occasional species the larger size of the left valves is noticeable.

The strange family Vulsellidae, which may be related to the isognomonids, has inequivalve representatives. Either valve may be the larger, but the left valve is the larger more commonly than the right. The valves of the vulsellids are often very irregular, but the inequivalve condition is not marked.

In the Placunidae, also, the left valves are commonly larger.

There is some variation as to which valve is the larger in the modern Pectinacea, but in all specimens that are strikingly inequivalve their right valves are the more convex and in most cases overlap the left. The right valves are larger in *Spondylus*, *Plicatula*, *Pedum*, the Cretaceous genus *Neithea*, and some *Pecten*, *sensu lato*. In a few modern pectens, however, the left valves are slightly larger than the right, and this condition is true also in the Propeamussiidae. Newell and Merchant (p. 175) note that the left valves are larger than the right in the late Paleozoic pectinacean genera *Aviculopecten* and *Pernopecten*, but the right valves are larger in specimens of the pterinopectinoid genus *Vertumnia*, which is confined to the Devonian Period. An analysis of the inequivalve condition among the pectinaceans might give some valuable data on the relationships of the many genera and subgenera within the superfamily.

Even a few of the fossil limids are inequivalve. Some Jurassic limids represented in the collection of the U. S. Geological Survey, mainly by those belonging to the genus *Ctenostreon*, have more convex right valves than left. Cox (1943, p. 153) in his description of the family characters of the Limidae made this statement: "There is no anterior subauricular notch like that found in many Pectinidae and Pteriidae, an anterior marginal gape for the protrusion of the foot and byssus affecting (if present) both valves equally." In living species the byssal gape

usually does affect both valves equally, but in some, almost always the strongly-ribbed ones, more of the byssal gape is in the right valve and in a few cases the gape is wholly in the right valve.

In the Ostreidae the left, or attached, valves are either equal in size to, or larger than, the right valves. This is equally true of such Mesozoic genera as *Gryphaea* and *Exogyra* as well as of living species of oysters.

The genus *Chondrodonta*, which is confined to Cretaceous rocks, is attached by its shell to the substrate. Like most ostreids, the attached (left) valves are always the larger. Because of the peculiar hinge and musculature, the systematic position of *Chondrodonta* is still in doubt, and it has been placed in the Ostreidae, Pectinacea, Pinnidae, and Mytilidae by various paleontologists.

On the other hand, the Anomiidae are attached to the substrate by their right valves, but the upper (left) valves are always larger. Likewise, in the aberrant Dimyidae, the left or unattached valves are the larger ones. Two interesting Upper Cretaceous genera, *Diploschiza* and *Pulvinites*, apparently are like *Anomia* and *Dimya* in that they are attached to the substrate by their right valves, and the unattached or upper (left) valves are the larger.

Some aberrant thick-shelled Jurassic and Lower Cretaceous pinnids are inequivalve. These forms are placed in the genera *Trichites* and *Stegoconcha*. In most cases the left valves are the larger.

It is worthwhile to pause here and summarize the data on the filibranchs thus far reviewed. The most noteworthy thing about this large order, with its numerous fossil as well as living representatives, is that the left valves are larger in the preponderance of inequivalve species. The exceptions to this are found in the Paleozoic pectinacean genus *Vertumnia*, most of the Mesozoic and Cenozoic Pectinidae, the Plicatulidae, the Spondylidae, a few of the Vulsellidae, and a few species of the Mytilidae. This, to my mind, has phylogenetic significance and a definite bearing on the classification of the order.

Another characteristic of the filibranchs with a well developed byssus is that where the byssal notch is confined to one valve, or is predominately in one valve, it is the right valve that has the notch or the larger portion of it. This is true of the Pectinacea, Pteriacea, Prionodonta, Anomiidae, Isognomonidae, Limidae (as pointed out previously), and undoubtedly others. I have made only a cursory survey of this characteristic and there may be some exceptions to this condition. However, the character is so consistent among the filibranchs that a definite phyletic unity is indicated. One other observation should be noted here. The pleurothetic filibranchs are more likely to have the byssal notch confined to the right valve. This is not always true, but it is certainly the common condition. On the other hand, some of the prionodonts are attached in a position so that the valve margins are perpendicular to the substrate. In many of these the byssal notch has migrated somewhat so that it is partly in each valve.

Beginning with the Unionacea there are several large families and superfamilies of pelecypods having less primitive ctenidial structure whose representatives, with few exceptions, are equivalve. Some of these exceptions may be unintentionally overlooked, as I have not attempted to trace all aberrant and obscure species of large taxa. Most of the aberrant species occupy a different ecologic niche from the main body of species of a family. Furthermore, in most of these cases either the right or the left valves may be the larger, as typified by *Beguina*, *Miltha*, and a few of the veneraceans.

Among the unionaceans (the Aetheriidae) a few African and South American species are found attached to the substrate by shell cementation. They may be attached by either valve, and either valve may be the larger; furthermore, there is no apparent correlation between which valve is attached and which is the larger. Lamy (pp. 144–151) describes and figures a few contorted and inequivalve specimens of the unionacean genera *Quadrula*, *Unio*, *Pseudospatha*, *Cuneopsis*, *Nodularia*, and *Arconaia*.

The Carditidae are a large and ancient family with nearly all its species equivalve; however, the aberrant genus *Beguina*, which lives in the Indo-Pacific region, is inequivalve, and either valve may be the larger.

Beguina lives surrounded by living coral. Many pelecypods with this type of habitat have either inequal or irregularly-shaped valves.

A few of the dreissenids are discordant, the right valves overlapping the left along a part of the posterior margin.

The inequivalve Rudistacea are among the most bizarre of all pelecypods. This large group of Jurassic and Cretaceous bivalves comprises species attached by either valve and in which either the left valve or the right is the larger. The inequivalve condition in the rudistaceans may be important to point to phyletic relationships within the superfamily.

One of the less primitive families which has very few inequivalve representatives is the Lucinidae. However, among the lucinids the genus *Miltha* has inequivalve species, and either valve may be the larger. Most species of the family Chamidae are also inequivalve, and here again either valve may be the larger. This inequivalve character is one of several indications of the close relationship between the lucinids and the chamids. Among inequivalve specimens of the latter group it is always the attached valves which are the larger.

Even the huge veneracean complex has a few inequivalve species. *Venerupis*, as well as the Petricolidae, have species in which either valve may be slightly larger than the other. In some species of *Claudiconcha* the inequivalve trait is very pronounced, the right valves consistently being the larger. In this connection, incidentally, it is noted that Cotton and Godfrey, in describing the genus, state (p. 248) that the right valve is larger than the left; furthermore, their figure of *Claudiconcha cumingi* (279, p. 247) shows the right overlapping the left, although in their description of this species (p. 249) they assert that the left valve overlaps the right.

Most of the Tellinidae are inequivalve in that the valve margins are sinuous and the posterior side of the shell is commonly bent to the right. In this very large family one finds that either the right valves or the left may be the larger in diameter or the more convex. Within a genus, however, the left or the right valves, as the case may be, are consistently the larger, and, as is the situation in the Pectinidae, a study of the relationships among the inequivalve genera may give some worthwhile suggestions as to the grouping within the family Tellinidae. For a more detailed account of the inequivalve condition in the Tellinidae, see Lamy (pp. 132–134).

A few of the semelids are also inequivalve. The larger number and generally more prominently inequivalve species have the left valves the larger, but in a few cases the right valves may be slightly the more convex. Like the tellinids, the posterior end of the shell is commonly bent, and the direction of bending is usually to the right, rarely to the left. Also like the tellinids, but more prominently and commonly so, the anterior end of the shell is bent in the direction opposite to that of the posterior end.

Most of the Sanguinolariidae are equivalve but a few species are not, the right valves being distinctly larger than the left. Like the Tellinidae, the posterior ends of some species are bent; but unlike the tellinids, they are bent to either the left or the right in about equal numbers.

The description of the inequivalve condition in the tellinids, semelids, and sanguinolariids shows some remarkable similarities and indicates a close relationship of these three families.

Many of the species belonging to the family Pleuromyidae (Triassic to Lower Cretaceous), including those of the genera *Pleuromya*, *Cercomya*, and *Gresslya*, have right valves which overlap the left valves along the dorsal border much like the condition found in some specimens of the Cenozoic family Myidae.

The corbulids are nearly all inequivalve, many markedly so, and the larger valves are invariably the right ones. A few of the related Myidae are also inequivalve, having in all such cases larger right than left valves, furthermore, when the valves of an inequivalve myid are closed the umbo of the right is higher than that of the left.

Among the inequivalve representatives of the lucinids, chamids, veneraceans, tellinids, sanguinolariids, pleuromyids, corbulids, and myids, the larger valves are commonly the right ones; and among those of the four last-named families it is invariably so. This situ-

ation is the opposite of that of the more primitive filibranchs.

The remainder of the pelecypod families discussed are generally inconspicuous groups either because of the small size of the shells or because the groups have small numbers of species and are geographically restricted. In this latter connection, some of the following taxa are not seen frequently because their representatives are restricted to deep water. The relationships of many of these families to each other or to their place in the classification of the Pelecypoda is not well understood. Moreover, their inequivalve condition is not consistent; among the inequivalve species of some families the larger valves are the right, of others they are the left, and of others they may be either one.

The Cleidothaeridae are like chamids in external appearance but are characterized by a pearly inner shell and a very different hinge. This family is confined to Australian and New Zealand waters. Specimens of the one living species are consistently attached by their right valves, which are much larger than their left valves.

In the Myochamidae, representatives of *Myochama* are attached to solid objects by the shells of the right valves, and the left valves are much larger and overlap the right. This condition is much like that found in the Anomiidae. Specimens of *Myodora*, on the other hand, are not attached, and the right valves are always larger, sometimes conspicuously so.

With the possible exception of a species of *Frenamya* which Cotton and Godfrey (p. 145) describe as having the right valves more convex than the left, all of the Pandoridae have the left valves larger than the right, and in some cases the discordancy between the valves is great, the left valves overlapping the right along the ventral border.

The Lyonsiidae are nearly all equivalve, but the few inequivalve species in this family have the left valves larger than the right.

In the Thraciidae the right valves are always larger.

Almost all of the periplomatids are inequivalve, and the larger valves are always the right ones.

Although there is little mention of it in the literature, the Poromyidae are also inequivalve. The right valve of a specimen overlaps the left valve slightly on both the dorsal and the ventral margins.

The Verticordiidae have an unusual type of inequivalve or discordant condition. The right valves overlap the left along the dorsal margin. This morphologic character is similar to that found in the Astartidae and Crassatellidae, but it is much more marked.

Many cuspidariids are inequivalve; the consistently larger left valves overlap the right valves along the posteroventral border.

In some species of Juliidae there are prominent spiral hornlike structures on the umbonal region of the right valves. This morphologic character is unique among the Pelecypoda. A drawing of the structure is given by Cotton and Godfrey (p. 129).

Of the 28 families with living species which are basically inequivalve (this eliminates such groups as the mytilids, carditids, lucinids, and venerids.) half, or 14 of them, have nacreous shells. This is an unusually high percentage as compared with the proportion of nacreous groups in the entire Pelecypoda. Nacreous shells in the Pelecypoda are, in general, considered a primitive characteristic. Whether the relatively high correlation between nacreous shells and inequal valves is significant or not awaits a survey of the nacreous groups in the entire Pelecypoda—a project that is greatly needed.

From the table which summarizes the data and from the more detailed discussion on the various groups, the consistency of the inequivalve trait obviously is important in the classification of the Pelecypoda. Some of the evidence from valve inequality merely substantiates the indications from other morphological characters, but, heretofore, the inequivalve trait has been ignored by taxonomists arranging a classification of the Pelecypoda. To be more specific, the consistently larger left valves found in the Prionodonta, Pteriacea, and Isognomonidae give an indication of relationship which is also borne out by other morphological characters. However, some caution must be exercised as to the interpretation of valve inequality in groups which have few inequivalve species, such as the mytilids and

PELECYPOD TAXA HAVING INEQUIVALVE REPRESENTATIVES

Taxa	The larger valve	
Aristerella		right
Cyrtodontidae[1] (*Heikea*)		right
Antipleuridae	left	right
Cypricardinia		right
Dexiobia		right
Pterineidae	left	
Leiopteriidae	left	
Myalinidae	left	
Pteriidae	left	
Mytilidae[1]	left	right
Prionodonta	left	
Bakevelliidae	left	
Inoceramidae	left	
Isognomonidae	left	
Vulsellidae[1]	left[2]	right
Placunidae	left	
Pectinacea (Paleozoic)	left[2]	right
Pectinacea (Mesozoic, Cenozoic)	left	right[2]
Propeamussiidae	left	
Spondylidae		right
Plicatulidae		right
Limidae[1]		right
Ostreidae	left	
Chondrodonta	left	
Anomiidae	left	
Dimyidae	left	
Pulvinitidae (including *Diplodonta*)	left	
Pinnidae[1] (*Trichites*)	left[2]	right
Unionacea[1] (Aetheriidae)	left	right
Carditidae[1]	left	right
Dreissenidae[1]		right
Rudistacea	left	right
Lucinidae[1]	left	right
Chamidae	left	right
Veneracea[1]	left	right[2]
Tellinidae	left	right
Semelidae	left[2]	right
Sanguinolariidae		right
Pleuromyidae		right
Corbulidae		right
Myidae[1]		right
Cleidothaeridae		right
Myochamidae	left	right
Pandoridae	left	
Lyonsiidae	left	
Thraciidae		right
Periplomatidae		right
Poromyidae		right
Verticordiidae		right
Cuspidariidae	left	
Juliidae		right

[1] Basically equivalve.

[2] Valve which is either more commonly the larger or more conspicuously so or both.

carditids. The few cases of inequal valves in these two groups undoubtedly mean little or nothing as an indication of phyletic relationships.

ACKNOWLEDGMENTS

I am particularly indebted to three persons for data and suggestions for this study. Dr. Roland W. Brown, of the U. S. Geological Survey, provided information on the spelling of some of the family names. Dr. Harald A. Rehder, of the U. S. National Museum, examined the manuscript for the usage and spelling of the pelecypod taxa. Dr. Horace B. Baker, of the University of Pennsylvania, pointed out Lamy's interesting paper.

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ACTIVITIES OF THE JOINT BOARD ON SCIENCE EDUCATION

EDITOR'S NOTE: Most members of the Academy are familiar with the name *Joint Board on Science Education*, but unfortunately few are familiar with its activities. Dr. Arnold H. Scott has kindly prepared this report on the Joint Board. Following this is a report by the Joint Board on a problem of interest to all scientists.

As early as 1949 the Washington Academy of Sciences became concerned about the need for encouraging the study of science and mathematics in the junior and senior high schools of the Greater Washington Area. Keith Johnson and Percy Rayford, of the District of Columbia Schools, had organized the first annual science fair for the Washington Area in 1947 and had begun asking the Academy for help in judging the entries. In 1951 a special committee was formed by the Academy with Dr. Martin A. Mason as chairman to organize a Junior Academy of Sciences. Upon its organization in 1952 the Junior Academy assumed the responsibility for promotion of the annual science fairs.

By 1951 some of the scientific and engineering societies had become concerned with the promotion of science education, and the schools were being contacted by the various societies who were wanting the privilege of presenting their programs to the students and working with them in the schools. As the work load of the teachers was heavy and the schedules rather tight, these requests from the societies for time became irksome to the school officials. It became clear to the D. C. Council of Engineering and Architectural Societies that something must be done to coordinate the activities of the societies and to establish better relations with the schools.

Early in 1952 Dr. W. T. Read, chairman of the Education Committee of the Council, took the first steps toward coordinating the efforts of the societies. He set up a Subcommittee for Secondary School Contacts with Walter H. McCartha as chairman, which secured approval of the school systems for the contact members to work with the science and mathematics teachers on behalf of the various societies wishing to help in encouraging the study of science and mathematics. The Washington Academy of Sciences was asked to join in this effort by appointing a parallel Subcommittee for Secondary Schools Contacts. This subcommittee was appointed with Dr. Arnold H. Scott as chairman. The first annual "List of Officials and Committees concerned with the Promotion of Science Talent" was published in the fall of 1952.

At first the teachers and school officials were suspicious of the efforts of the scientists and engineers, as they were afraid that an effort would be made to try to change their methods of teaching. However, the early efforts of the contact members were very tactful, and the teachers soon came to realize that the contact members could be really helpful to them. The influence and size of the contact committee grew rapidly. The parallel efforts of the Washington Junior Academy of Sciences in promoting science fairs in the schools resulted in a rapid growth of interest by the students in the fairs. It then became apparent that a more formal coordinating organization was needed.

Under the active direction of Dr. Margaret Pittman, then president of the Academy, the Joint Board on Science Education was formed in 1955 by an agreement between the Washington Academy of Sciences and the D. C. Council of Engineering and Architectural Societies. Its first chairman was Dr. Raymond Seeger. It was empowered to direct its activities "toward assisting and counseling the faculties of schools and related organizations, with power to initiate action where desirable, and to raise funds to carry out the various activities of the Board." These activities include:

"1. Providing such speakers as may be desired.
2. Arranging for classroom demonstrations.
3. Assisting in developing graduate school opportunities for science teachers and aiding them in finding summer employment.
4. Recommending changes in science courses when deemed advisable.
5. Sponsoring local area fairs and assisting in planning, and promotion of same."

The Board consists of 12 members, 6 appointed by the chairman of the Council and 6 appointed

by the president of the Academy. The terms of office are three years, two members being appointed each year from each of the parent organizations. The official year starts on June 1, and the new officers are elected at the first meeting of the new year. The chairman is chosen alternately from the members of the Academy and the Council. The Board has been incorporated so as to establish responsibility and provide for tax exemption on donations made to the budget of the Board.

Each committee of the Board is headed by two members from the Board, one from the Academy and one from the Council. Other members of the committees are recruited from interested persons in the various scientific and engineering societies.

The Secondary Schools Contacts Committee is the largest committee of the Board and is composed of some 135 persons who act as contact members to the junior and senior high schools of the Metropolitan Washington Area (within a radius of 25 miles of central Washington). There is one contact member for each junior and senior high school of the area with a few exceptions. Because of the size of the committee and magnitude of the work to be done, the committee has been divided into eight divisions, roughly paralleling the school systems involved. The contacts committee serves as a channel through which the various scientific and engineering societies can aid the teachers and also as a channel through which the science and mathematics teachers can call on the talents of the members of the scientific and engineering societies.

The work of the Contacts Committee is planned and reviewed by a Planning Committee, which is composed of the chairman and vice-chairman, the Division chairmen, and the school liaison officers. The latter are persons appointed by the school systems to work with the Joint Board.

It is the duty of the contact member to make the acquaintance of the science and mathematics teachers in his school so that they may feel free to call upon him for whatever help he can give. He is prepared to help in getting speakers for career days, science clubs, school assemblies, etc. He can help in getting scientific films for use in schools and in getting volunteers for project judging, project counseling and other work connected with science fair operations. The contact member is expected to make sure that there has been no failure of the school and students to receive information about the special scientific lectures which are presented each year especially for the high-school students and to help when necessary in obtaining the necessary tickets for these lectures. It is the stated policy of the Joint Board that once each year, if the schools desire it, scientists shall be brought into the classrooms to discuss their work in science and engineering with the purpose of creating interest in these subjects. When such a program has been planned and arranged between the Joint Board and the school system, it is the duty of the contact member to see that all the requests have been filled, that both the teacher and the scientist or engineer are well informed of what is expected of each, and that the program works smoothly in his school. Three such programs have been carried out and have received a very enthusiastic response.

A meeting in honor of the Secondary Schools Contacts Committee members for their faithful work with the schools was held on October 14, 1957. Remarks of appreciation were made by Dr. John K. Taylor, chairman of the Joint Board, Dr. Arnold H. Scott, chairman of the Secondary Schools Contacts Committee, and Dr. T. Edward Rutter, division superintendent of the Arlington Public Schools. A feature of the meeting was a preview of the film entitled "The Strange Case of the Cosmic Rays," which is the third of the Bell System Science Series. The film was introduced by Dr. Ralph Bown, chairman of the Scientific Advisory Board of the Bell System Science Series and former vice chairman-Research of the Bell Telephone Laboratory.

The Committee on Science Fairs was organized to act as a general coordinating body for science fair problems. It works with the school staffs and the Washington Junior Academy of Sciences by:

1. Advising on ground rules,
2. Advising on policy matters,
3. Aiding in securing proper consultants for projects (this is usually a matter of assisting the School Contact Members when necessary),
4. Advising on safety problems as needed,
5. Aiding in securing judges,
6. Aiding in securing accessory support, particularly special exhibitions in the Smithsonian Institution, National Institutes of Health, and tours of these and other government institutions such as the National Bureau of Standards,
7. Aiding in the guidance of publicity,
8. Working with other groups such as the Prince Georges Science Fair Association, the Arlington County Science Fair Association, Science Associates of Montgomery County, and other similar groups and,

9. Cooperating with other groups to raise the necessary money where such is not available from the School Boards.

Four area science fairs are held each year. Two winners from each area fair are sent to the National Science Fair, along with one teacher from each area acting as chaperone.

The Finance Committee is charged with preparing a budget for the Joint Board and seeking a means for raising the funds required for this budget. The budget for the present year is as follows:

Expenses of chairman and vice-chairman		$125.00
Secondary School Contacts Committee		400.00
Science Fairs Committee:		
(a) Local Area Fairs	$1,200	
(b) National Fair	2,500	3,700.00
Science Teacher demonstration awards		525.00
Finance Committee		200.00
Miscellaneous		550.00
		$5,500.00

Money to support this budget is expected from the scientific, engineering, and architectural societies, commercial organizations in the area, certain service organizations, and individual donations. In the past the Washington Junior Academy of Sciences has liberally supported the budget by its donations from the funds received from the scientific trips which it sponsors. Many more individual donations are needed if the budget is to be adequately supported.

A curriculum committee has made a study of the scientific curriculum of a local school system at the request of an official of that system. A report of this committee has been made available to all the school systems of the Washington Area who desire it.

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A Report by the Joint Board on Science Education in the Greater Washington Area

SCIENCE CURRICULA IN SECONDARY SCHOOLS

About a year ago the Joint Board was invited by a local school system to make recommendations on science curricula in secondary schools. After a brief, intensive study, based upon an extensive background of experience of the science community, the following report was submitted by a special Science Education Committee. The requesting group is of the belief that the general recommendations may be of value to other schools with similar problems; accordingly, the Board has been authorized to make its views known to all the schools under the Greater Washington Area.

Recognizing that the problem of science teaching is of great concern, both nationally and internationally, and not merely of a local character, the Science Education Committee recommends schools continue to study vigorously the revision of its curricula in mathematics and science at the secondary-school level with the following principles in mind:

FUNDAMENTALS

Outside a genuine need to interest all capable secondary-school students in the scientific aspects of the universe in which we all live, most college scientists of all disciplines are agreed that the primary requirement for college is general preparation in reading, writing, and arithmetic (the 3 R's), stressed at all grades from kindergarten through the secondary school, with particular emphasis upon mathematics and its relationship to the sciences, and not merely the specific courses in the sciences. Of paramount importance is the motivation of students through enthusiastic, content-informed teachers. The need to challenge intellectually the competent, as well as to safeguard the right of the slow-to-learn, must be a primary concern of all engaged in a democratic educational system.

GUIDANCE

Guidance about the professions is needed for "guidance personnel." So-called guidance, at

present, seems to be concerned mostly with informing students as to what they should do if their careers or colleges have already been selected. Much more important is insuring that the student has an opportunity to select among careers those in which he has a particular interest and potentiality, even if both are latent.

Local scientists are available through the Joint Board on Science Education for general presentations to guidance personnel and for specific assistance to individual students, as well as for group talks.

DEPTH AND BREADTH

A greater emphasis is needed upon depth of understanding a few principles of science rather than upon an encyclopedic coverage of many topics about science. The student needs to know much more than just facts of science; he needs to understand primarily "the why," secondarily "the how," and only thirdly "the what." At all grades, from the kindergarten through the secondary school, science should be taught, not chiefly to acquire "information, please," but primarily to stimulate curiosity and to implement interests through well-selected facts, as a means —not an end in itself. The criterion of success should be whether or not a student is able to think and behave differently about the scientific material of his environment at the conclusion of his course. Above all, he should be made familiar with both the power and the limitations of science.

COURSE OBJECTIVES

Each course should have clearly stated, practicable objectives, including the means of measuring such objectives. Evidence should be annually shown as to the measured success of achievement of such objectives. Critical objective analysis should be continually made of all administrative procedures, which may prevent the optimum realization of teaching objectives.

EXPERIMENTATION IN COURSES

The secondary schools should develop objectives of their own without undue regard for opinions of high school teachers as to what they believe is, or should be, truly college preparatory. In this connection, the requirements and use of high-school subjects by colleges and universities nationally should be continually examined, particularly in consultation with local college scientists.

Serious consideration should be given to the ordering of courses, including possible modification of traditional arrangements; for example, the order of physics and chemistry which in high school is sometimes opposite to that usually found in colleges; the giving of algebra as a 2-year sequence rather than having it interrupted by geometry, which may be (or should be) little used in later secondary physics and chemistry classes. In this connection, it is noted that some peculiar choices may be accidentally given students; for example, the need to choose at a particular time between a future required course (history) and one elective course (in biology). In this instance it would be preferable to give a choice among comparable subjects, say, a group of sciences or a group of social studies.

Experimentation with new types of courses in mathematics, biology, chemistry and physics should be encouraged on an interschool basis by a few capable teachers of honor courses. Under no circumstances, however, should a radical change be made in the general program without considerable experimentation and the preparation of adequate texts. Promiscuous tampering with the bad material may affect good material also. Possible new courses are: (a) introductory courses in mathematical sciences, which involve the use of numerical analysis and the applications of mathematics to science; (b) introductory courses in physical science, which may combine present courses in physics and chemistry (one semester of each)—not a "survey" course; (c) introductory courses in modern mathematics, including certain fundamental concepts in algebraic geometry, elementary calculus, and statistics.

Local scientists might be invited through the Joint Science Board on Education to participate in continuing studies of such science curricula. There might be a series of round table discussions in which an equal number of scientists from a particular discipline in local universities would be invited to meet with an equal number of high-school teachers in that discipline, a selected number of these conferees might be invited to another round table in which some educational authorities, both within the local public school system and from neighboring groups, would also be invited to participate.

MODERN VIEWPOINTS

All material should be presented to the student at his own psychological and intellectual levels. It should be presented, moreover, as living mathematics and science—that is, from a modern viewpoint of science as science with only minor consideration of technological importance, which would appear to be more appropriate in social study courses. (General science courses, indeed, should be more scientific and less social in emphasis.)

LABORATORY

Good laboratory work is regarded as being highly important. There is a serious question, however, as to how much of real value is being accomplished in single periods of instruction (in lieu of a double period), particularly when such periods may be arbitrarily shortened for various administrative reasons throughout the year. Here, above all, objectives should be continually examined and evaluations made annually.

In this connection, more allowance should be made for a teacher to make ready for laboratory just prior to the class meeting. Sufficient time must be allowed in the class for the student to assemble simple (inexpensive) apparatus. There is a tendency in a large class to mechanize all operations in order to achieve efficiency, whereas the sine qua non of all laboratory work should be encouragement of the individuality of each student. Consideration should be given to different patterns for different types of students; for example, voluntary science-fair projects for the more imaginative (not all), laboratory repetition of demonstrations for the less imaginative (not all), etc.

IN-SCIENCE TRAINING

In view of the increasing complexity of modern science, it is recommended that in-service training groups be established at all levels of mathematics and science teaching, but particularly at the elementary levels. Equally important as new factual information are new ways of presenting old basic materials. Local scientists might be invited through the Joint Board on Science Education to assist in such courses.

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Men should be taught as if you taught them not,
And things unknown proposed as things forgot.
—POPE.